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Chesapeake Sediment Synthesis

Reviewing sediment sources, transport, delivery, and impacts in the Chesapeake Bay watershed to guide management actions
v2.1

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U.S. Department of the Interior
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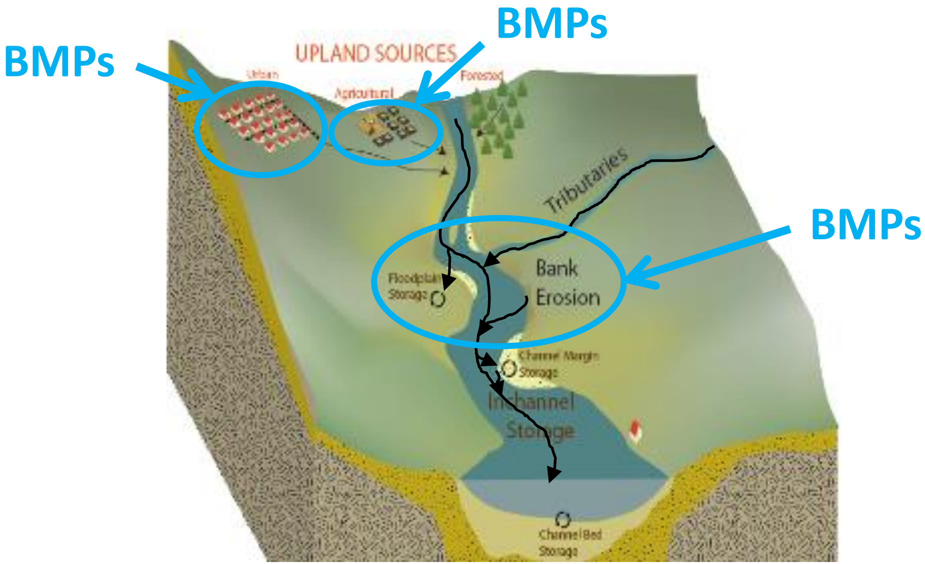
Goal of the synthesis

Summarize the state of knowledge of sediment in the Chesapeake Bay watershed

… to guide management actions on the landscape for the restoration of the watershed and estuary.



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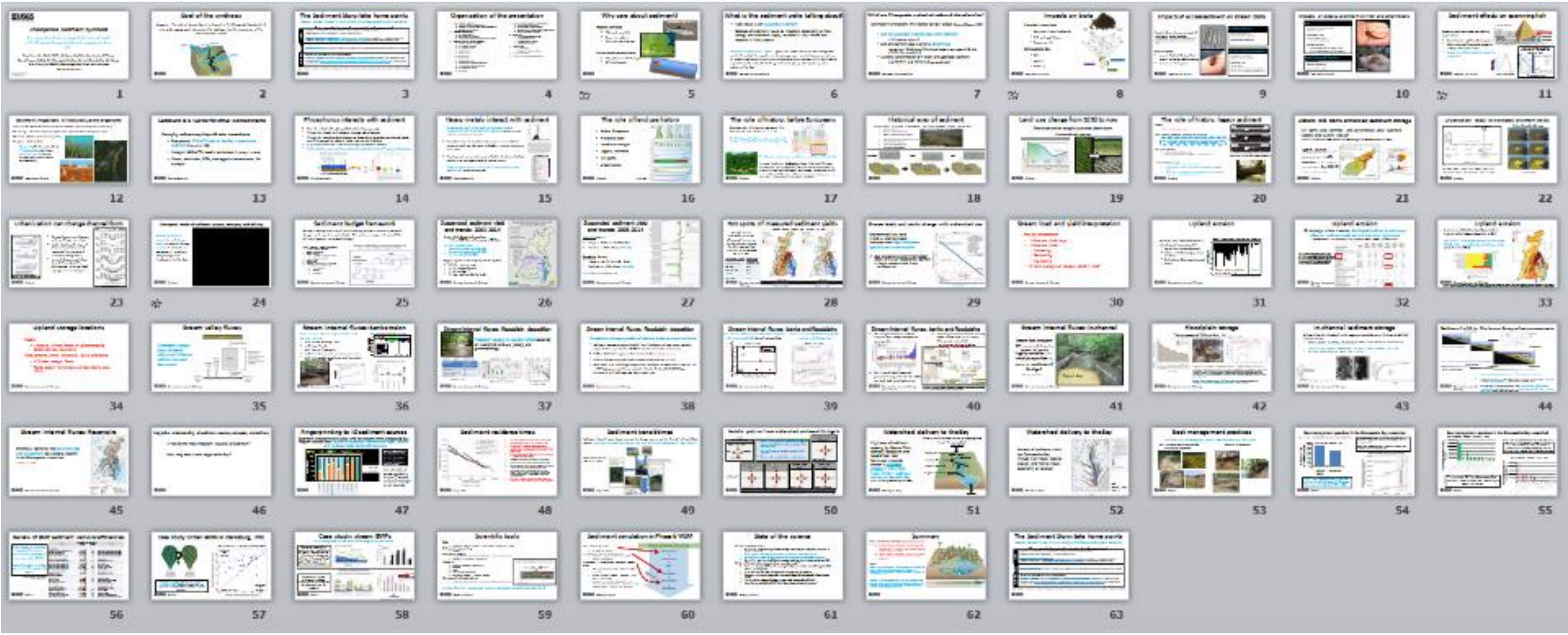
Organization of the presentation



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The Sediment Story: take home points

Excessive sediment harms fish and wildlife in the Chesapeake Bay and its watershed

Three important geomorphic principles to guide management:

Scale

Sediment started in uplands and is now moving through stream storage compartments

Sediment processes differ in headwater streams than in larger rivers

Sediment 'hops and rests' downstream, in and out of different storage zones (like floodplains), trapping large amounts of sediment (and nutrients), and causing lag times (sometimes fast, often slow) of response to management actions

Time

Historical legacy matters for understanding current sediment issues, and may impact BMP and management effects on loads

Land Use

Nutrients and other pollutants are attached to sediment

Agricultural, developed land, and stream banks are all important sources of sediment, but locally and temporally variable

Based on models, BMPs are expected to have reduced the 2014 sediment load to streams by about 23% in the Chesapeake Bay watershed

New scientific advances continue to improve our ability to understand and manage local and regional sediment problems

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Organization of the presentation

1. **Why care about sediment?**
   - Impacts on biota, nontidal and tidal
   - Sediment as a vector for nutrients and contaminants
   - Sediment characteristics
2. **The role of land use history**
   - Before Europeans
   - Historical eras of sediment
   - Land use and river management changes over time
3. **Sediment sources, transport, and delivery**
   - Sediment budget framework
   - Stream loads and yields
   - Stream load trends
   - Upland erosion
   - Upland storage
4. **Stream valley fluxes**
   - Bank erosion
   - Floodplain deposition
   - The balance of erosion and deposition
   - In-channel erosion and deposition
   - Stream valley storage
   - Reservoirs
5. **Integrative understanding of sources and delivery**
   - Fingerprinting to ID sources
   - Residence times and path lengths
   - Holistic pictures from watershed sediment budgets
   - Watershed delivery to the Bay
6. **BMP effects**
   - Tracking BMP implementation
   - Modeled BMP effects
   - Review of BMP efficiencies
   - Newer BMP examples
7. **Scientific tools**
   - Phase 6 model
   - New measurement capabilities
8. **State of the Science**
9. **Summary for watershed management**

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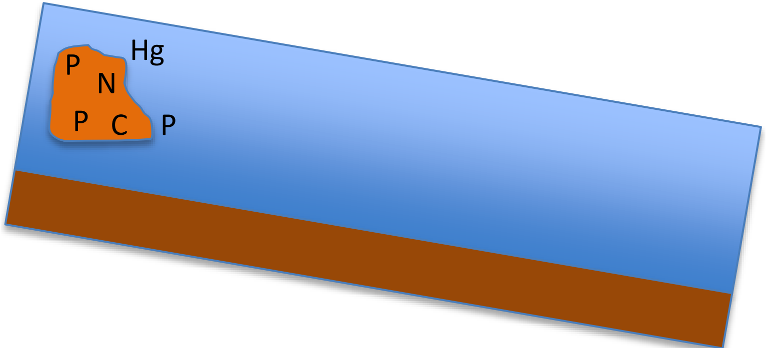
Why care about sediment?

Impacts on biota

- Tidal and nontidal
- Grain size matters
- Multiple mechanisms

Associated contaminants

- Phosphorus, and Nitrogen
- Other chemicals



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What is the sedient we're talking about?

- Most focus is on **suspended sediment**
- Bedload of sediment could be important depending on flow energy and sediment supply, but data is very limited and material is likely coarse

Sediment characteristics matter (grain size, organic content, mineralogy, and metal chemistry) for impacts on stream organisms, controlling concentrations of sorbed and constituent nutrients/pollutants on sediment, the likelihood of export from the watershed, biogeochemical cycling, and impacting water clarity in the Bay.

What are Chesapeake watershed sediment characteristics?

At 9 major river stations (RIM) before delivery to Bay: (Zhang and Blomquist 2017)

- **90% of suspended sediment load is fine sediment**

  (< 63 microns; clay + silt)

- 11% of sediment load is organic, **89% mineral**

  (converting POC/SS ratio at RIM stations to organic using organic/POC ratio of 0.35; Noe unpublished)

- Average concentration of P and N on suspended sediment:

  1.0 mg-P/g, 3.6 mg-N/g (Zhang unpublished)

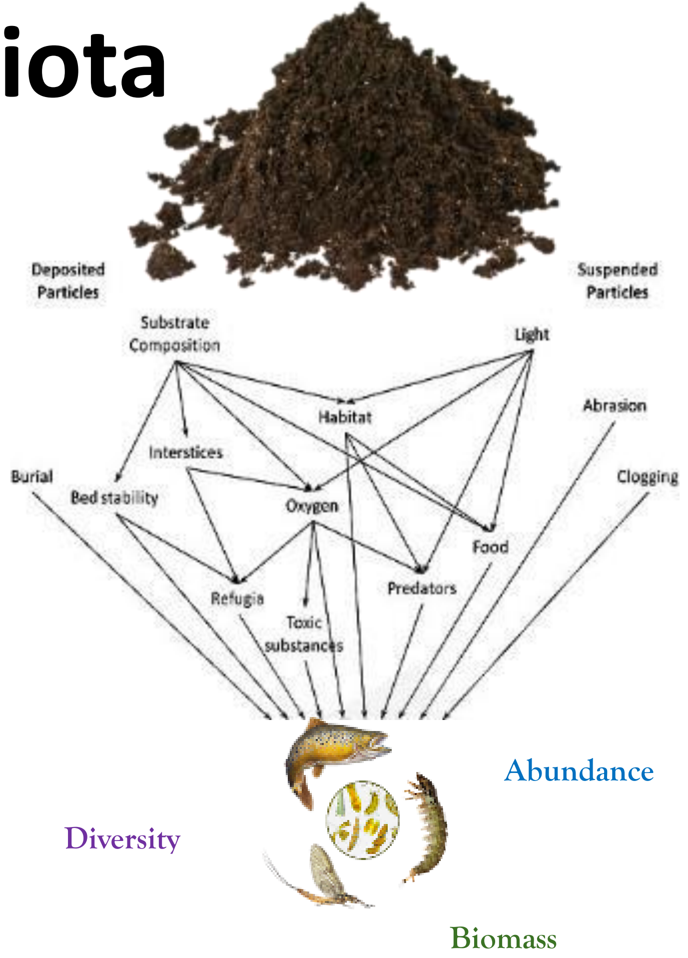
Impacts on biota

Nontidal watershed

- General effects, foodwebs
- Fish and amphibians
- Spawning fish

Chesapeake Bay

- SAV
- Oysters / benthos



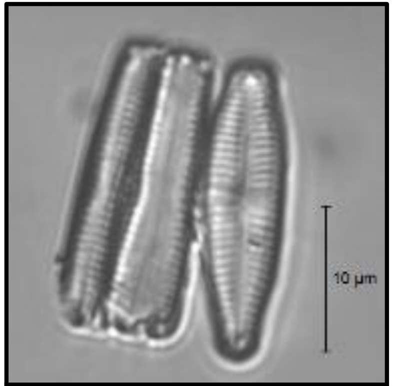
Impacts of excess sediment on stream biota

Long history of science on impacts of sediment on stream biota

(Cordone & Kelley 1961, Chutter 1969, Ritchie 1972, Newcombe & MacDonald 1991, Ryan 1991, Waters 1995)

General Effects

- Loss of habitat (fills interstitial spaces, anchoring, substrate coating)
- Loss of sensitive species



Primary Producers

Abrasion of periphyton

Covering periphyton and plants

Reduced primary productivity

Benthic Macroinvertebrates

Loss of interstitial habitat

Feeding issues (filter feeders)

Respiration issues

Increased drift

Loss of sensitive species (EPTs) to more tolerant taxa (chironomids and oligochaetes)

Impacts of excess sediment on fish and amphibians

Fish

Reduced adult foraging efficiency

Avoidance of areas

Reduced pool habitat

Loss of spawning habitat

- Interstitial spaces filled

Reproductive success

- oxygen deprivation in salmonid redds
- Larval salmonid mortality (entrapment)

Amphibians and Reptiles

Reduced habitat

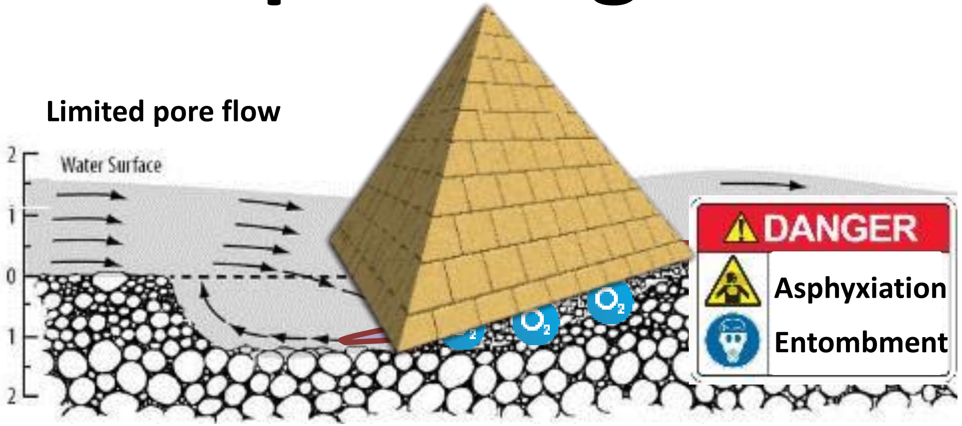
Coating of eggs masses

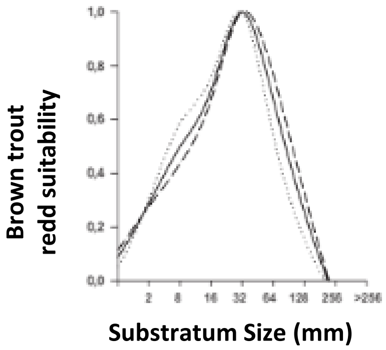
Loss of sensitive species

Sediment effects on spawning fish

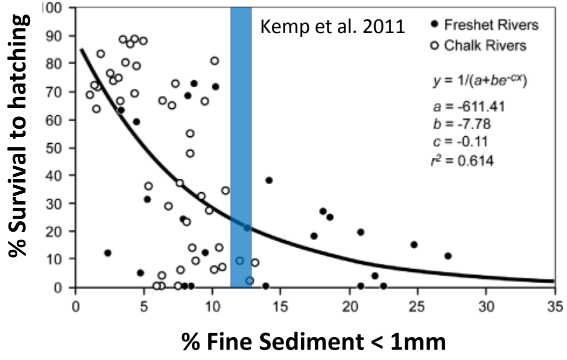
Spawning and recruitment can limit fish populations

- Gravel-spawning fish need clean gravels
- Adequate pore-flow provides oxygen to embryo and removes waste
- **Spawning redds vulnerable to excess fine sediment**





Consistent threshold of reduced survivorship with ~10-20% bed fine-sediment by weight



Sediment negatively effects estuarine organisms

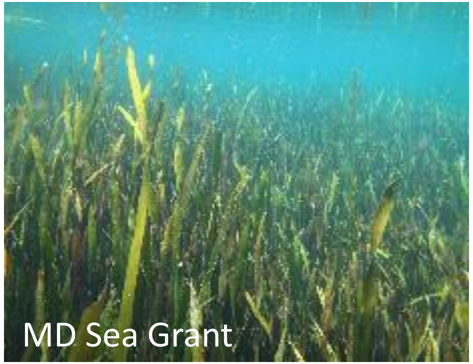
Watershed sediment delivered in floods has a dramatic short-term impact on water clarity

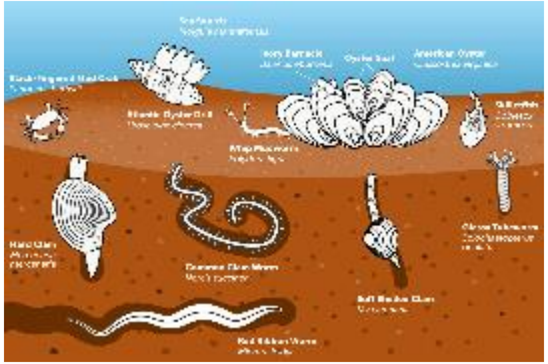
On average, internal resuspension may be more important than contemporary inputs

Effect of sediment inputs varies regionally

Negative effects on biota:

- **Seagrass** (light attenuation; burial)
- **Phytoplankton** (light stress)
- **Macrobenthic** community biomass and structure (burial; contaminants)





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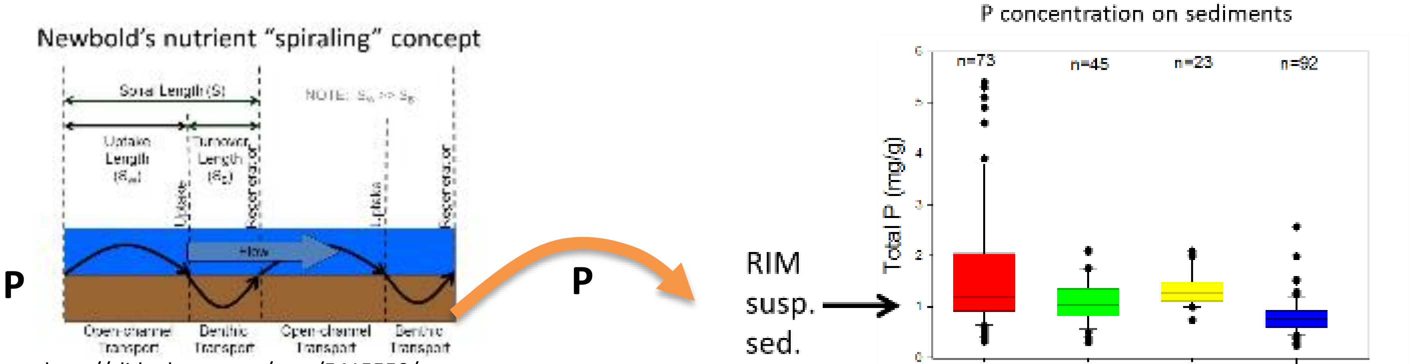
Sediment is a vector for other contaminants

Managing sediment may help with other contaminants

- Phosphorus: **77% of TP load to the Bay is attached to sediment** (Zhang et al. 2015)
- Nitrogen: 18% of TN load is particulate N (Zhang et al. 2015)
- Metals, pesticides, PCBs, and organic contaminants, for example

Phosphorus interacts with sediment

- Most P is attached to sediment, but not all of it permanently
- Phosphate interacts with sediment in storage and in transport
- Phosphate sorbs/desorbs and changes in bioavailability depending on redox and pH, and could be managed in sediment storage locations like floodplains
- P spirals downstream, in and out of storage, on and off of sediment
- **Understanding sediment helps understand most, but not all, of P transport downstream**



http://slideplayer.com/user/5415550/

Pocomoke River, MD-DE; Mattawoman Creek, MD; Little Conestoga Creek, PA; Laurel Hill, PA; Linganore Creek, MD; Upper Difficult Run, VA (Gellis et al., 2009; Sloto et al., 2012; Gellis et al., 2015)

Heavy metals interact with sediment

- **Heavy metals (such as Hg) sorb to sediment and are transported and deposited with sediment** (Skalak and Pizzuto 2010, Flanders et al. 2010, Skalak and Pizzuto 2014)

- Remobilization of stored contaminants is a result of fluvial processes and can take years to decades (Skalak and Pizzuto 2010, Skalak and Pizzuto 2014)

- Contaminant concentration can often be a function of sediment particle size or organic content (Skalak and Pizzuto 2014)

- **Many heavy metals are enriched in sediment from urban watersheds** (Horowitz and Stephens 2008)

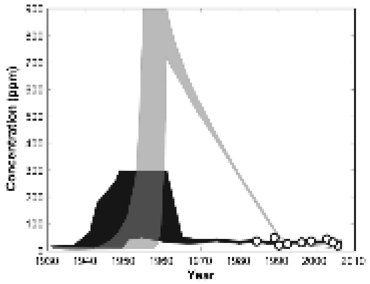
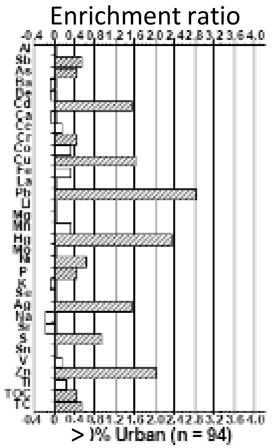


Figure 10. Mercury concentration on suspended particles transported by the South River from 1930 to 2007. The gray region represents model reconstructions based on the age and Hg concentration distributions observed in FGCM deposits in 2007. The black region defines the history documented by the Dooms Dam core (range is defined by the 95% confidence intervals associated with radiometric dating; Skalak and Pizzuto, 2010). Circles are samples from FGCM deposits dated by bomb radiocarbon (data from Skalak and Pizzuto, 2010).



Horowitz and Stephens 2008

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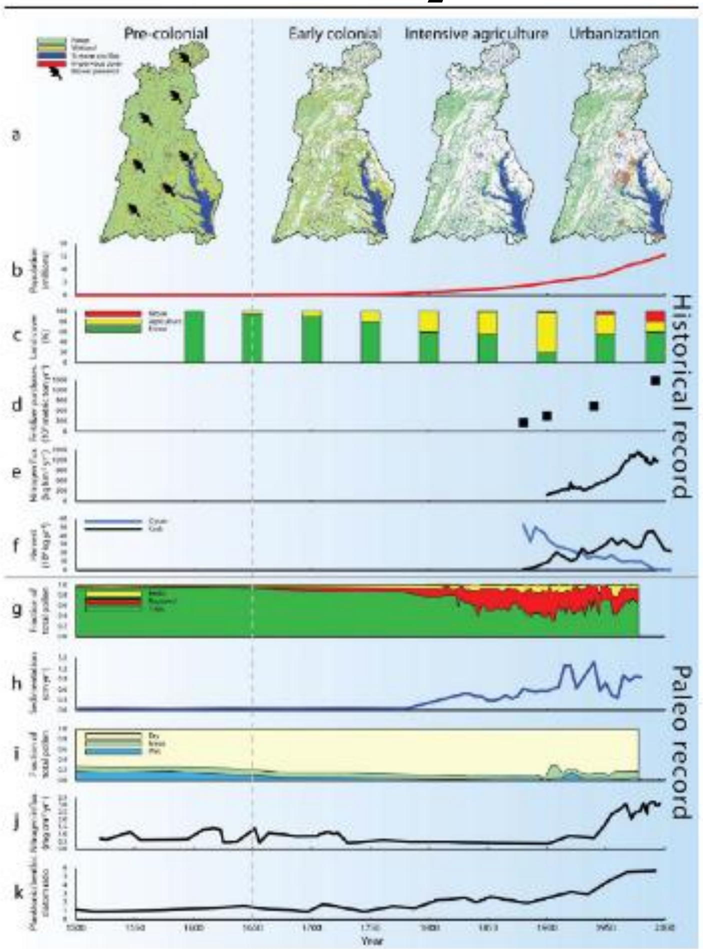
The role of land use history

- Before Europeans
- Historical eras
- Land use changes
- Legacy sediment
- Mill dams
- Urbanization



Brush 2008

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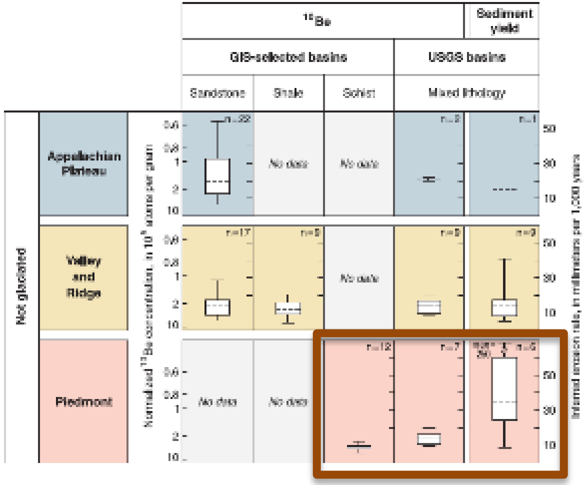
The role of history: before Europeans

Geologic rates of erosion vary across the Chesapeake watershed (Gellis et al. 2009)

The Piedmont had low natural sediment yields, in contrast to its current high yields



Pre-European Holocene condition: very different than today

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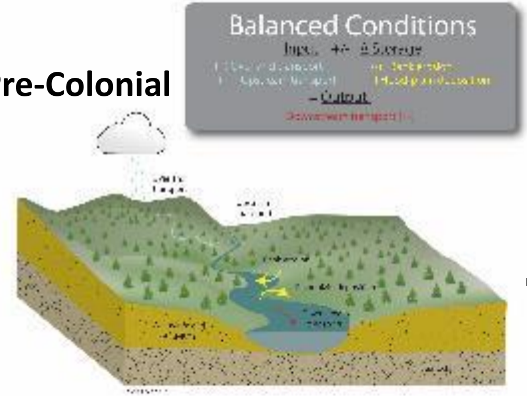
In some locations, <u>headwater</u> streams (likely not the larger streams and rivers) may have had low banks, anastomosing channels, and wetland marsh and swamp floodplains (Elliott et al. 2013), with much beaver influence (Ruedemann and Schoonmaker 1938, Brush 2009), … but more research is needed.

Historical eras of sediment

Different historical eras changed stream conditions and created the sediment problems we have today

- Demise of beavers
- Deforestation and land clearing
- Upland erosion and agricultural land use
- Wetland drainage and stream channelization
- Build up of legacy sediment
- Industrialization and mill dams
- Soil conservation and BMPs

Pre-Colonial



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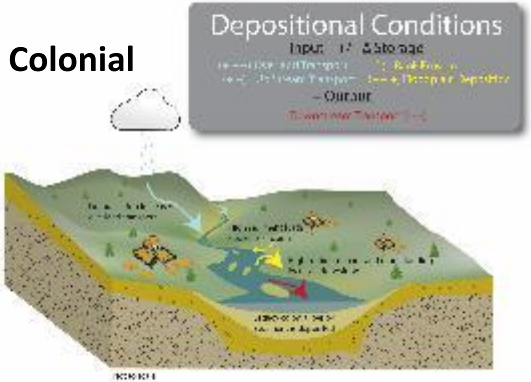
Colonial



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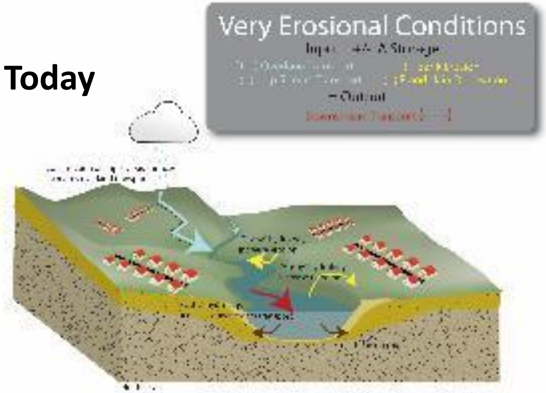
Today



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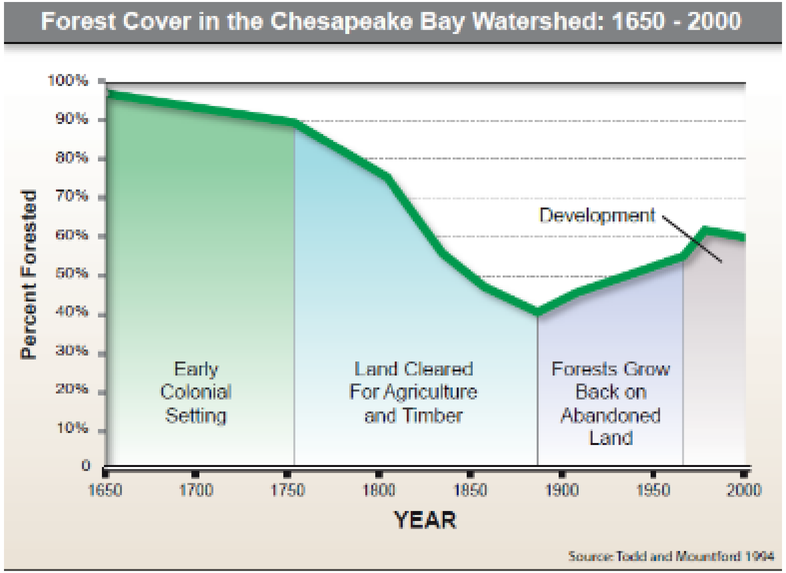
Land use change from 1650 to now

Forest conversion to agriculture and urbanization

increased soil erosion



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The role of history: legacy sediment

Definition (2017 STAC workshop)

"For the purposes of the Chesapeake Bay management effort, we would define legacy sediment as sediment stored in the landscape as a byproduct of accelerated erosion caused by landscape disturbance following European settlement."

What it means for landscape processes and restoration

There is a large amount of sediment stored in the fluvial landscape that sets the current impaired conditions and processes that need to be measured and managed to influence stream habitat and downstream loads

How much and where

- Legacy sediment thickness varies
- Some stored sediment is pre-colonial (Pizzuto et al. 2017)
- New remote sensing and GIS tools can estimate locally

Important because legacy sediment can:

- **increase sediment loads as it is mobilized**
- **create long lag times of stream response to upland BMPs** (see later slides)
- **impair a local waterway even if current landuse may make it seem like it should be a reference "undisturbed" site**

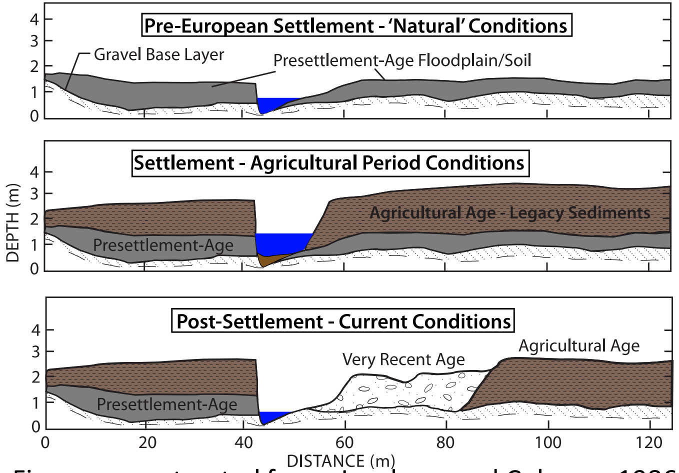

Figure reconstructed from: Jacobson and Coleman 1986

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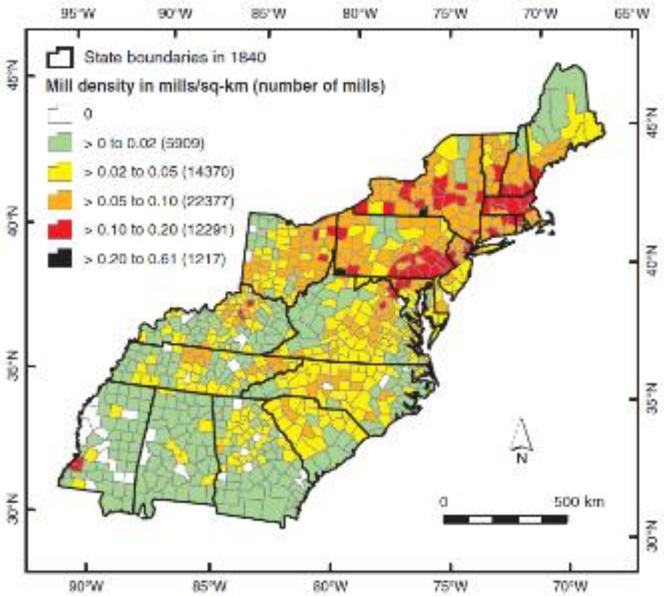
Historic mill dams enhanced sediment storage

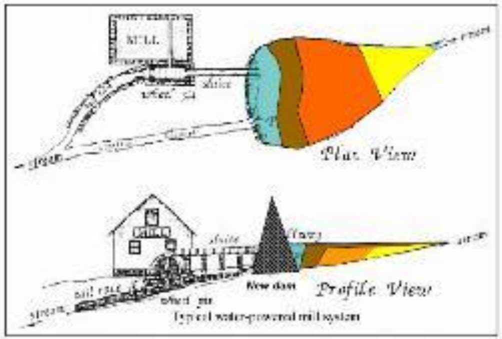
Mill dams were common, and can enhance local sediment storage and current erosion

(Walters and Merritts 2008, Merritts et al. 2011, Hupp et al. 2013, Donovan et al. 2016)

>65,000 water-powered mills in **872 counties** in the eastern United States **by 1840**

(Walters and Merritts 2008)





Courtesy Franklin & Marshall College

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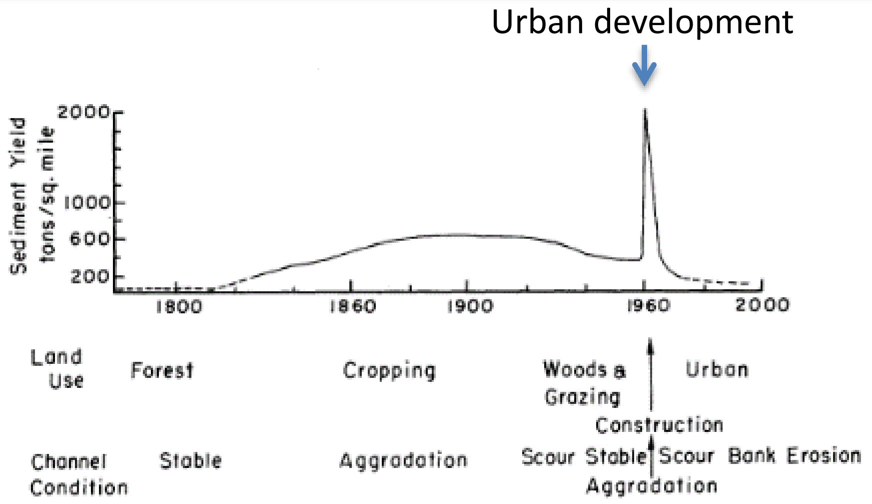
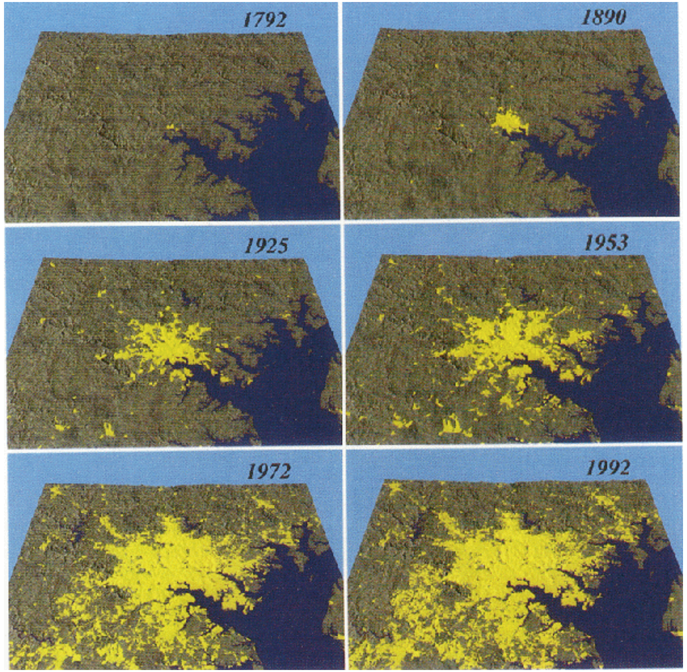
Urbanization leads to increased sediment yields



Wolman 1967

Urban Growth in Baltimore



Foresman 1998

But newer findings suggest that sediment export after construction remains high for decades (Gellis et al. 2017)

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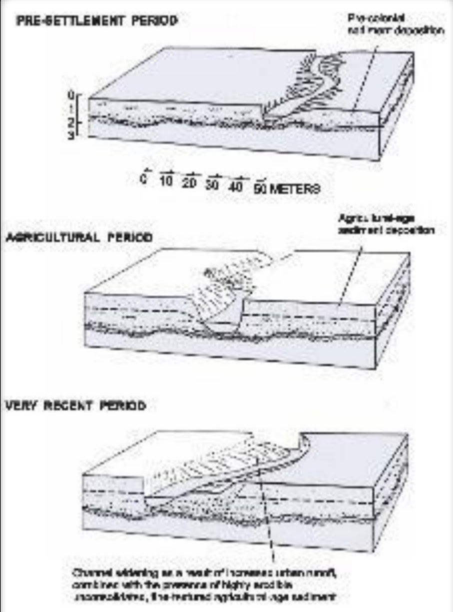
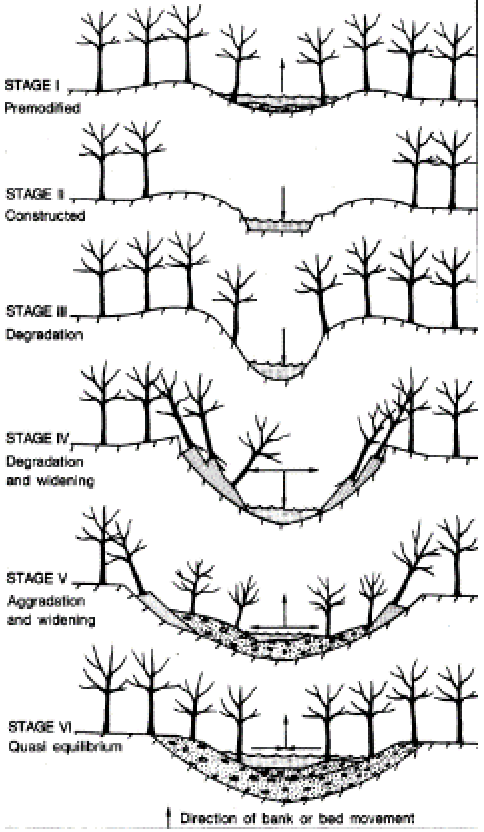
Urbanization can change channel form



Langland and Cronin, WRIR03-4123
Modified from Jacobson and Coleman, 1986

- Stream channels are dynamic and can change over time.
- Understanding the stage of channel evolution can be important for stream and sediment management.
- Incised channels, which are found throughout the Chesapeake, often go through a progression of changes.

Channel Evolution Model



(Simon and Hupp 1987)

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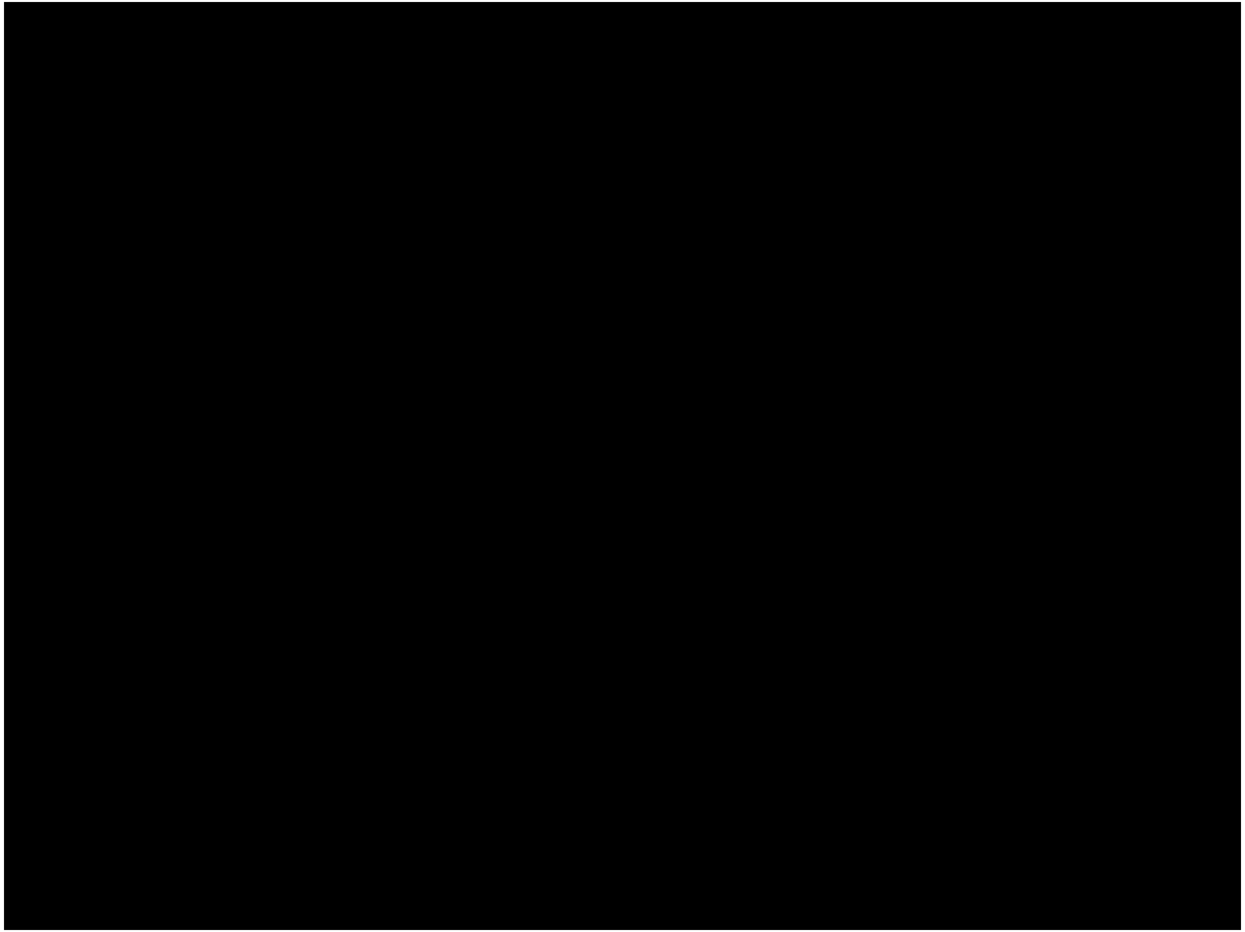
Conceptual model of sediment sources, transport, and delivery

Sediment sources, transport, and storage zones in watersheds vary as a result of land use, management practices, and geology, from headwaters to the Bay



USGS *Source, transport, delivery*

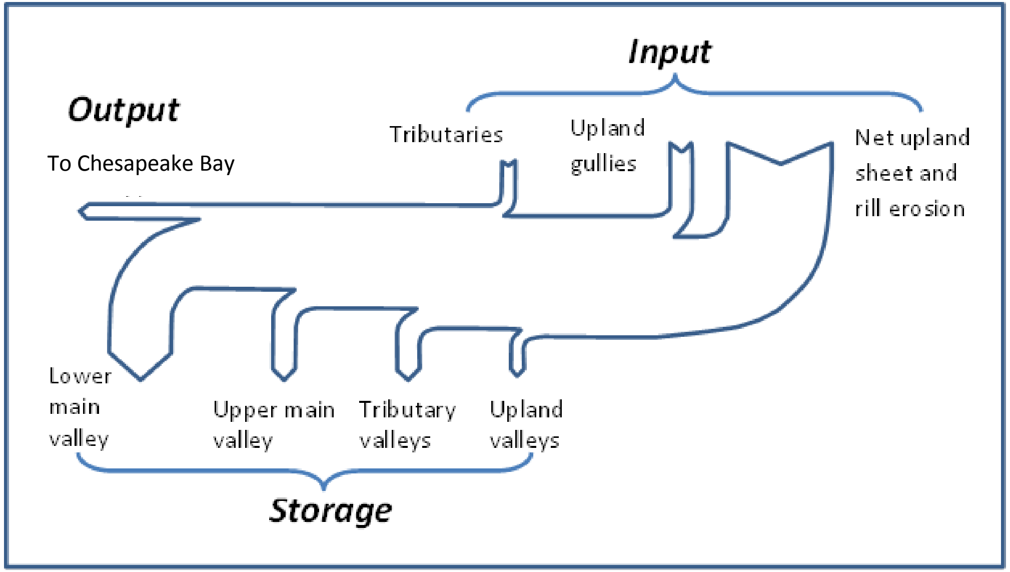
Sediment budget framework

Sediment budgets are useful for describing sediment sources, transport, storage, and export in watersheds. This section is organized around the different parts of a sediment budget:

Typical sediment budget components:

1. Integrated upstream input
2. Downstream output
3. Upland sources
   - Erosion of first order channels
   - Overland rill erosion
4. Tributary input
5. Bank erosion
6. Floodplain storage and surface erosion
7. In-channel storage and erosion
   - Margin deposits
   - Point bars
   - Channel bed

Hypothetical sediment budget for the Chesapeake Bay watershed. Thickness of the arrows indicates amount of sediment.



Suspended sediment yield and trends: 2005-2014

Suspended sediment yields range from:

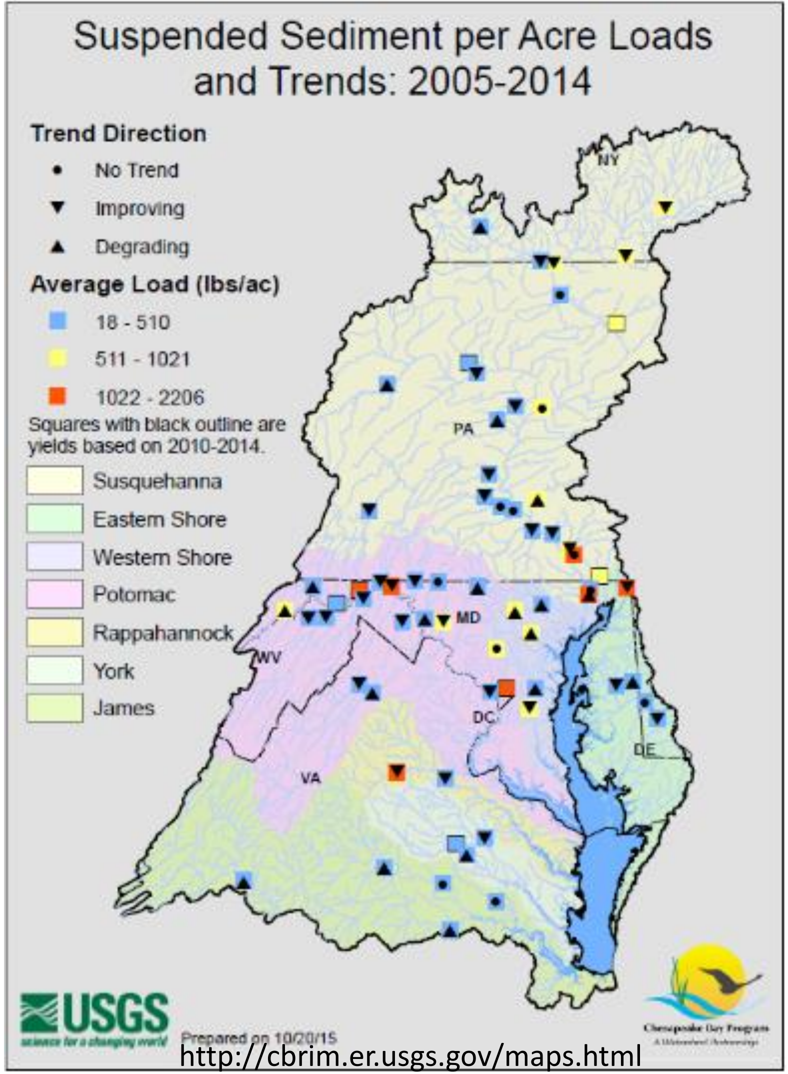
18 to 2,206 lbs/ac with an average of 482 lbs/ac

Trends in sediment loads:

- **Improving trends = 29 of 59 (50%)**
- **Degrading trends = 19 of 59 (30%)**
- **No trend = 11of 59 (20%)**

Of the 7 stations with the highest yields of suspended sediment:

- 3 have improving trends
- 1 has a degrading trend
- 1 has no trend
- 2 have insufficient data for trends



http://cbrim.er.usgs.gov/maps.html

Suspended sediment yield and trends: 2005-2014

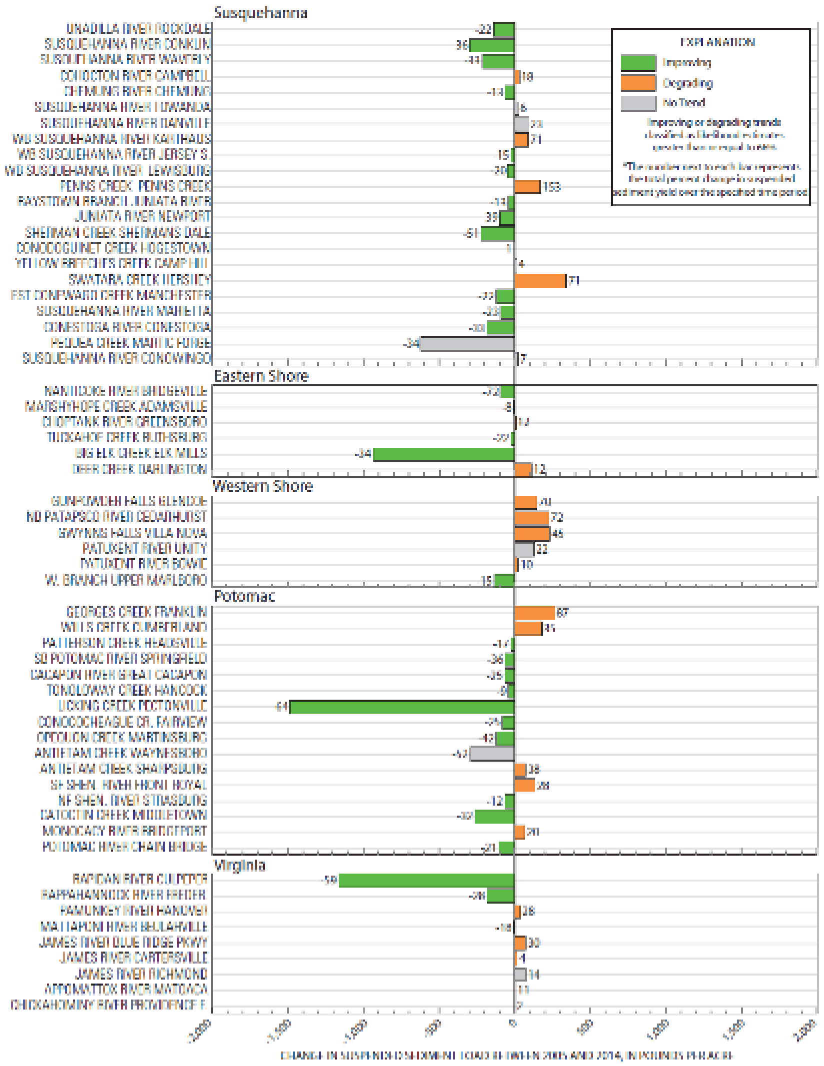
<u>Improving</u> Stations

- Range = -8.11 to -1,490 lbs/ac
- Median = -221 lbs/ac **(-29.4%)**

<u>Degrading</u> Stations

- Range = +4.75 to +341 lbs/ac
- Median = +118 lbs/ac **(+42.8%)**

http://cbrim.er.usgs.gov/maps.html



Hot spots of measured sediment yields

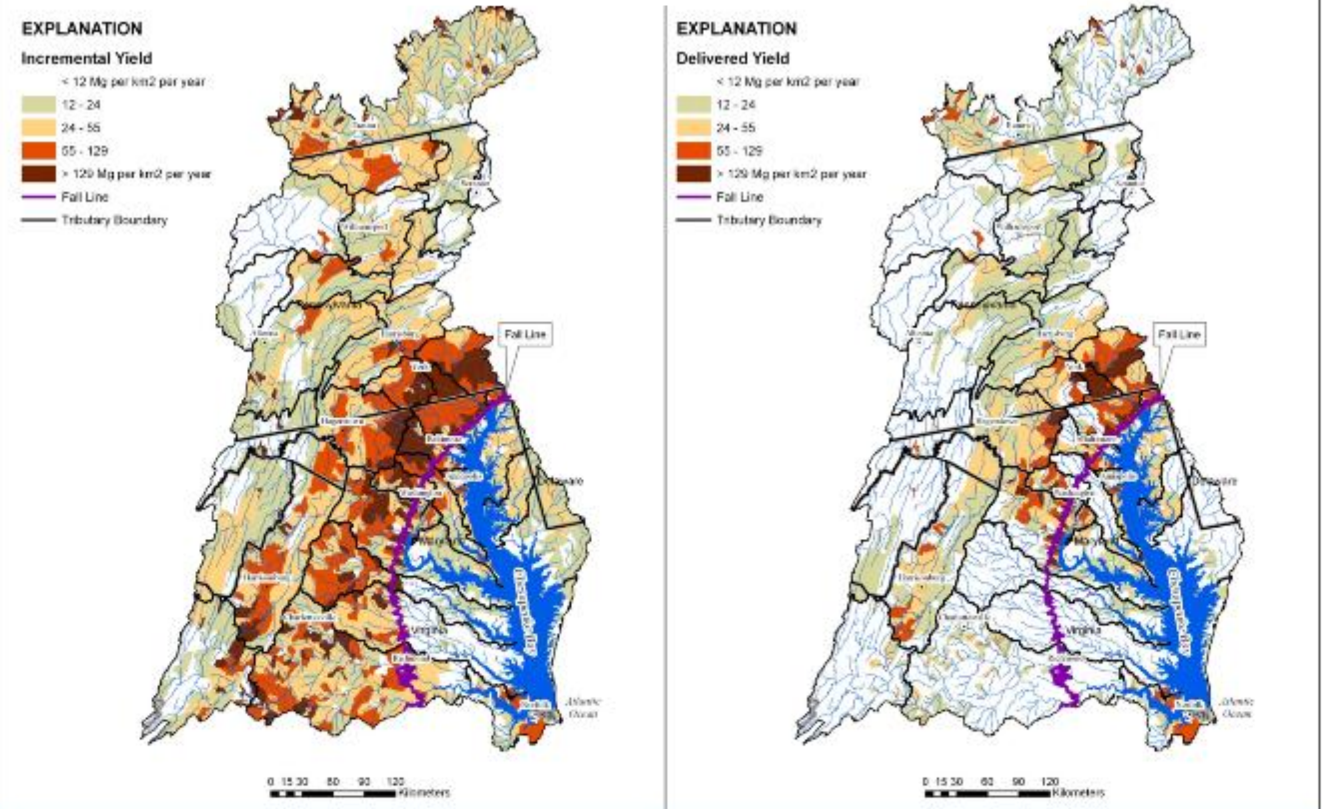
Average annual sediment yields by physiographic province for 65 stations draining the Chesapeake Bay Watershed, 1952–2001

(Gellis et al. 2009)

Physiographic Province	Sediment yield ($Mg/km^2/yr$)
Appalachian Plateau	58.8
Blue Ridge	56.8
Valley and Ridge	66.3
Piedmont	**103.7**
Coastal Plain	11.9

Source, transport, delivery

SPARROW modeled sediment yields (Brakebill et al. 2010)



Incremental Yield	Delivered Yield
Input to streams	Delivered to Bay

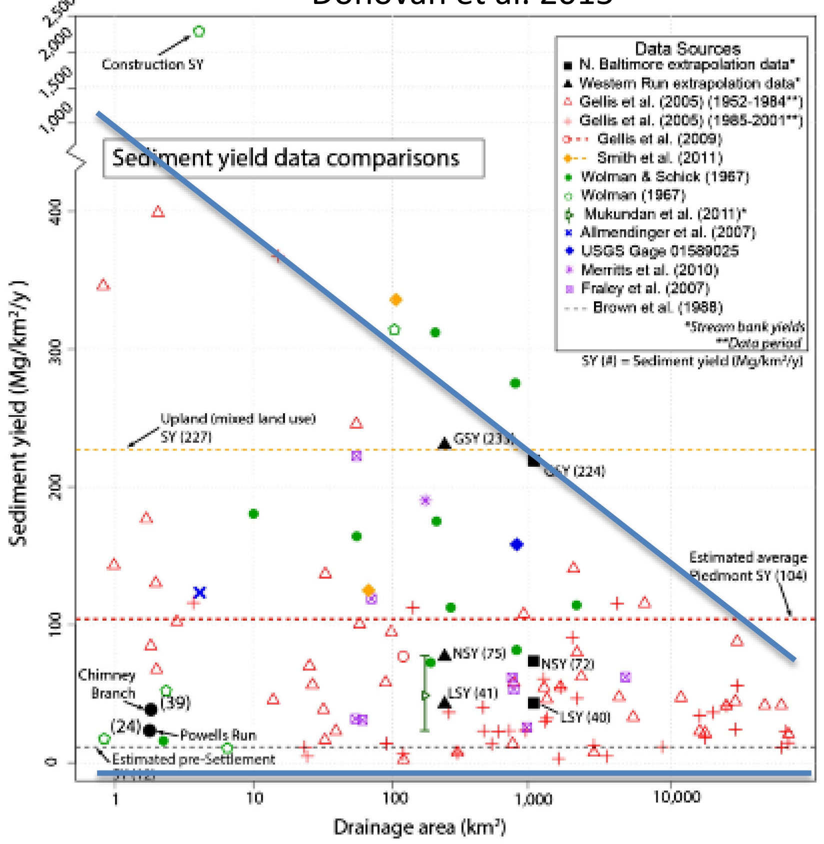
Stream loads and yields change with watershed size

Sediment delivery ratio
(yield vs. drainage area)
indicates that **larger catchments typically have smaller yields**

- due to spatial averaging of erosion rates, or fluvial trapping of sediment in larger streams and rivers

(Smith and Wilcock 2015)

Donovan et al. 2015



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Stream load and yield interpretation

½ of rivers have improving sediment loads

- A few rivers have greatly improved
- The rest are slightly better or slightly worse
- Western Shore is getting worse

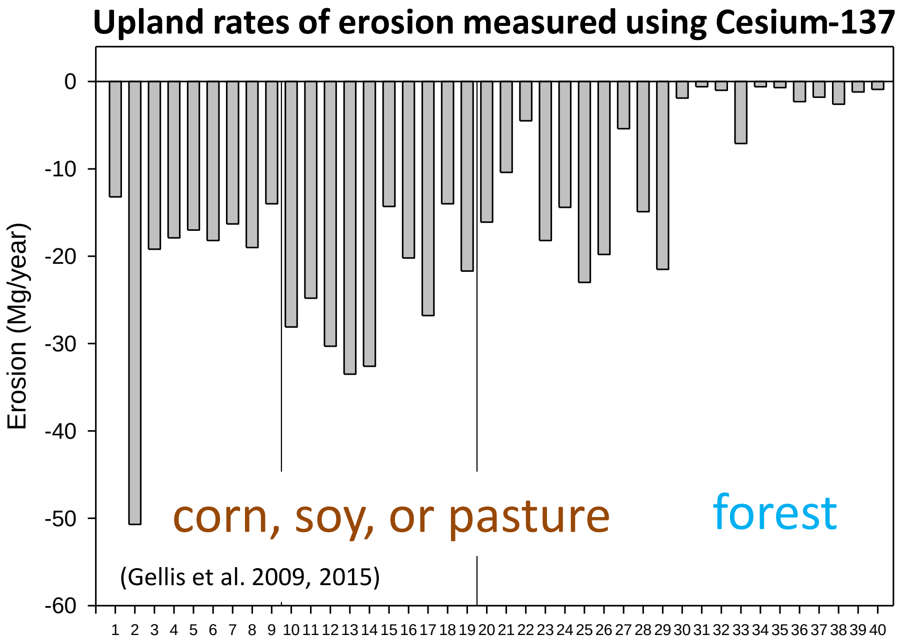
Piedmont has the largest sediment yield, Coastal Plain the smallest

Smaller watersheds have larger sediment yields

Upland erosion

What are the important sources of sediment from uplands?

- Agriculture (cropland, pasture)
- Urban, suburban (turfgrass, street residue)
- Disturbance (development, mining)
- Forest



Source, transport, delivery

Upland erosion

On average, where it occurs, **developed land has a much larger effect on sediment loads per unit area than agriculture**

(SPARROW model: V1 = RF1, a much coarser scale; Brakebill et al. 2010, V2 = NHDplus; Brakebill et al. 2017)

This information is preliminary or provisional and is subject to revision. It is being provided to meet the need for timely best science. The information has not received final approval by the U.S. Geological Survey (USGS) and is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information."

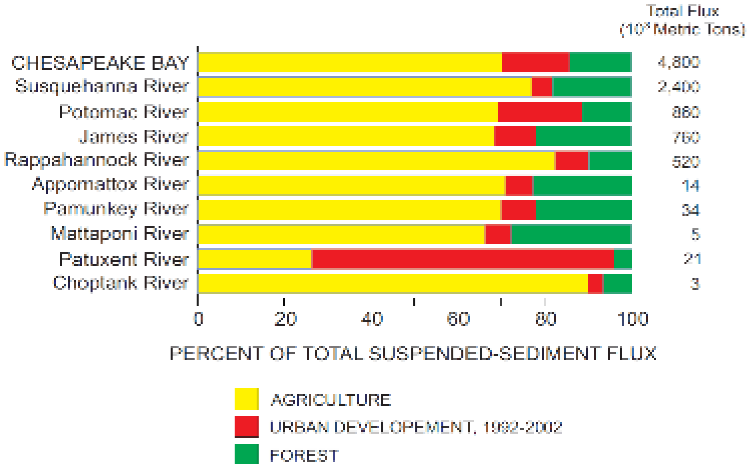
Explanatory Variable	Coefficient Units	SS02V1 Mean Coefficient	SS02V1 Standard Error	SS02V1 Probability Level	SS02V2 Mean Coefficient	SS02V2 Standard Error	SS02V2 Probability Level
Sediment Sources							
Length1 < 35 CFS Above the Fall line (AFL)	$Mg\,m^{-1}yr^{-1}$	0.291	0.132	0.015	X	X	X
Length2 < 35 CFS Below the Fall Line (BFL)	$Mg\,m^{-1}yr^{-1}$	0			X	X	X
Agriculture	$Mg\,km^{-2}yr^{-1}$	56.962	11.988	0	71.024	15.019	<0.001
Development	$Mg\,km^{-2}yr^{-1}$	3920.41	1370.077	0.003	2041.51	1096.131	0.032
Forest	$Mg\,km^{-2}yr^{-1}$	0.985	1.412	0.248	5.634	2.977	0.03
Land-to-Water Delivery							
Basin Slope	dimensionless	0.061	0.035	0.084	X	X	X
Dam Density	dimensionless	-22.966	9.819	0.021	X	X	X
Soil Permeability	dimensionless	-1.195	0.515	0.022	X	X	X
Piedmont Uplands	dimensionless	0.961	0.313	0.002	0.1	0.031	0.001
K Factor	dimensionless	X	X	X	0.77	3.013	0.002
Aquatic Storage Above the Fall Line (AFL)							
Storage1 > 35 < 120 CFS	day^{-1}	0			X	X	X
Storage3 > 120 < 250 CFS	day^{-1}	0			X	X	X
Storage5 > 250 CFS	day^{-1}	0			X	X	X
Aquatic Storage Below the Fall Line (BFL)							
Storage2 > 35 < 120 CFS	day^{-1}	0			X	X	X
Storage4 > 120 < 250 CFS	day^{-1}	2.54	1.02	0.007	X	X	X
Storage6 > 250 CFS	day^{-1}	1.921	0.859	0.014	X	X	X
Storage, all streams BFL	day^{-1}	X	X	X	1.27	0.419	0.003
Aquatic Storage from Reservoirs							
Reservoir Settling Velocity	$m\,yr^{-1}$	234.918	127.339	0.034	137.45	61.05	0.013

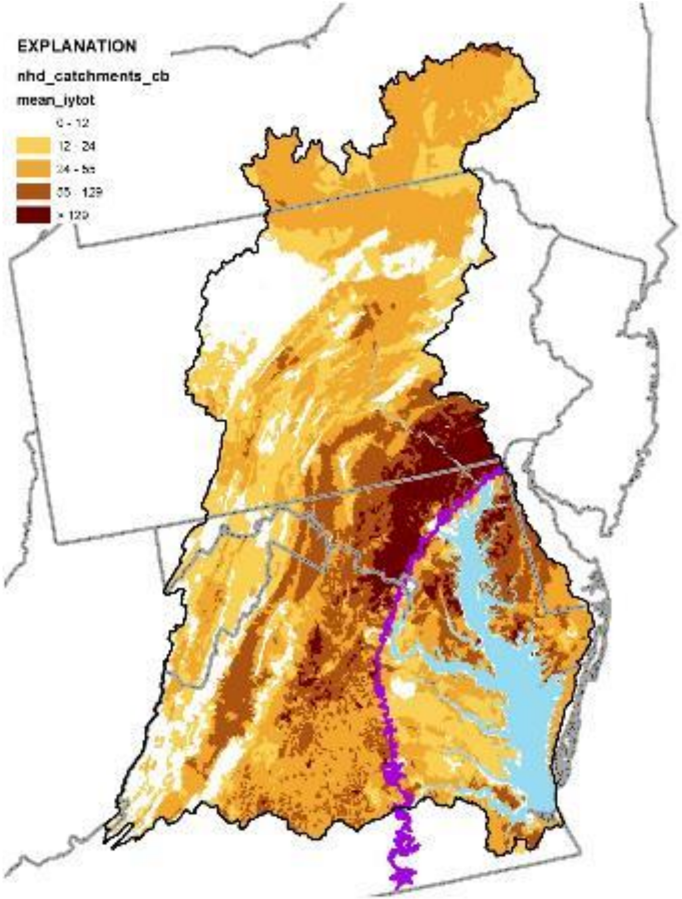
USGS *Source, transport, delivery*

Upland erosion

Local suspended sediment yields generated are highest in the Piedmont (Brakebill et al. 2017)

Agriculture is widespread, and these areas contribute ~69% of the suspended sediment to Chesapeake Bay (Brakebill et al. 2017)

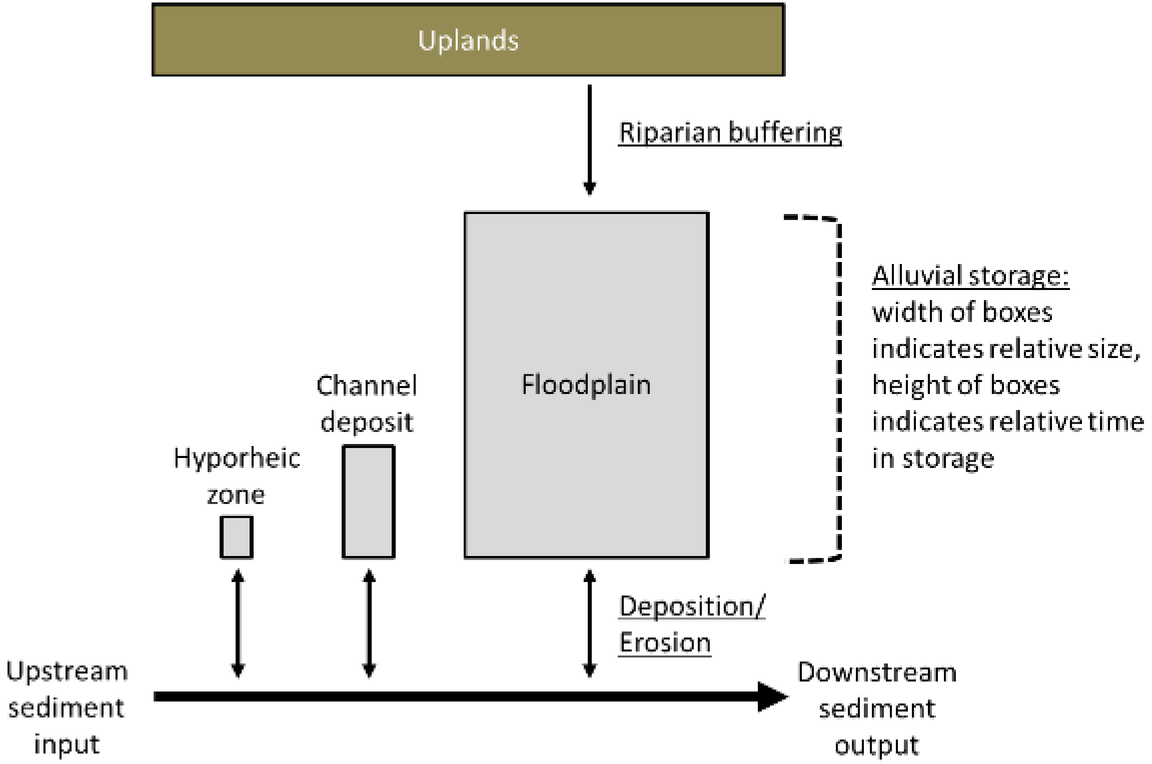




USGS *Source, transport, delivery*

Stream valley fluxes

Geomorphic storage zones of stream valleys can influence sediment transport downstream

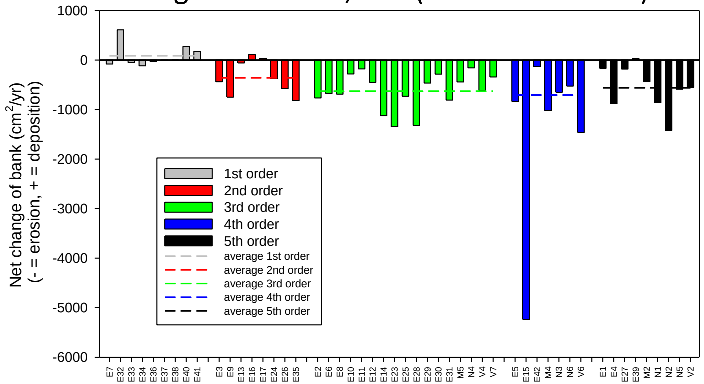


Stream internal fluxes: Bank erosion

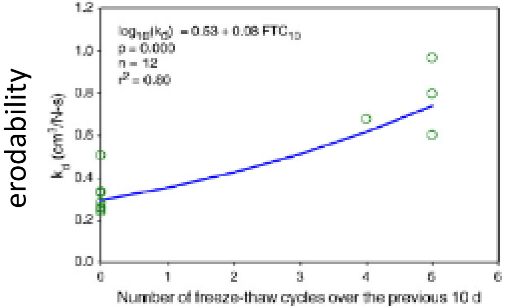
Bank erosion rates are highly variable, and typically increase:

- with stream drainage area
- with large floods
- with freeze-thaw cycles
- with less dense soil (Wynn and Mostaghimi 2006)
- with less woody vegetation and less roots (Wynn and Mostaghimi 2006)

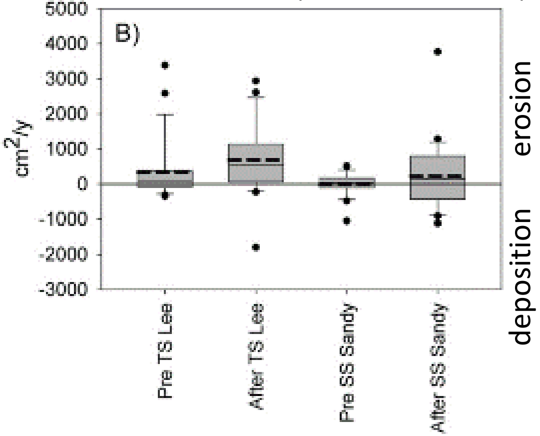
Linganore Creek, MD (Gellis et al. 2015)



Stroubles Creek, VA (Wynn et al. 2008)



Difficult Run, VA (Gellis et al. 2017)



USGS *Source, transport, delivery*

Stream internal fluxes: floodplain deposition

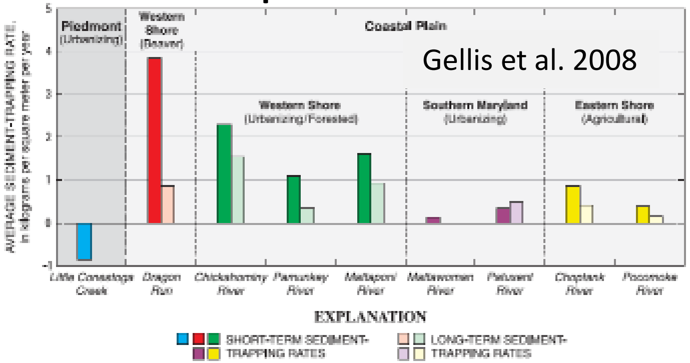
Floodplain trapping is spatially variable depending on watershed land use, geology, and geomorphology

Piedmont floodplain sedimentation

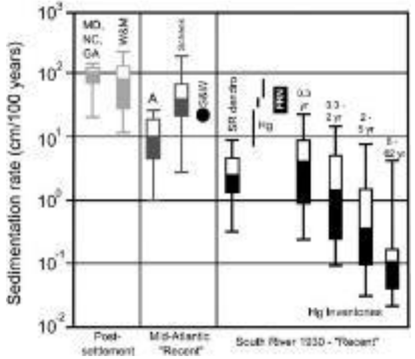
Watershed	Floodplain sedimentation ($kg\ m^{-2}\ yr^{-1}$)
Difficult Run	6.5
Little Conestoga Creek	4.9
Linganore Creek	9.8

Schenk et al. 2013

Chesapeake watershed



Blue Ridge / Valley and Ridge



Pizzuto et al. 2016

Source, transport, delivery

Stream internal fluxes: floodplain deposition

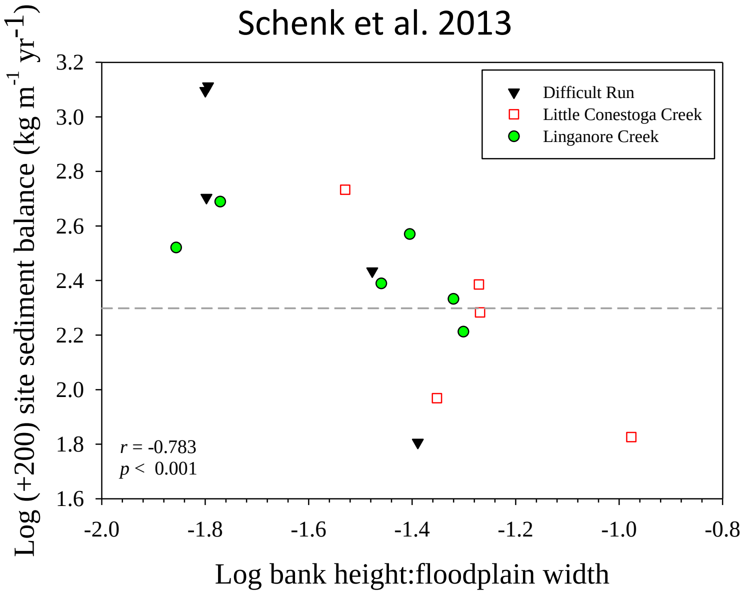
Floodplains can trap quantities of sediment similar to annual river loads:

- Sediment accumulating on Coastal Plain floodplains of large rivers typically trapped the equivalent of **119% of annual river loads** (Noe and Hupp 2009)
- **95%** in 147 km^2 Linganore Creek watershed (Maryland; Gellis et al. 2014)
- **52%** in 14 km^2 upper Difficult Run watershed (Virginia; Gellis et al. 2017)
- SPARROW: 2.2 x 10^6 Mg/yr trapped by floodplains on Coastal Plain rivers, vs. 7.3 x 10^6 Mg/yr generated from uplands of watershed, and 3.0 x10^6 Mg/yr delivered to the Chesapeake Bay (Brakebill et al. 2010)

Stream internal fluxes: banks and floodplains

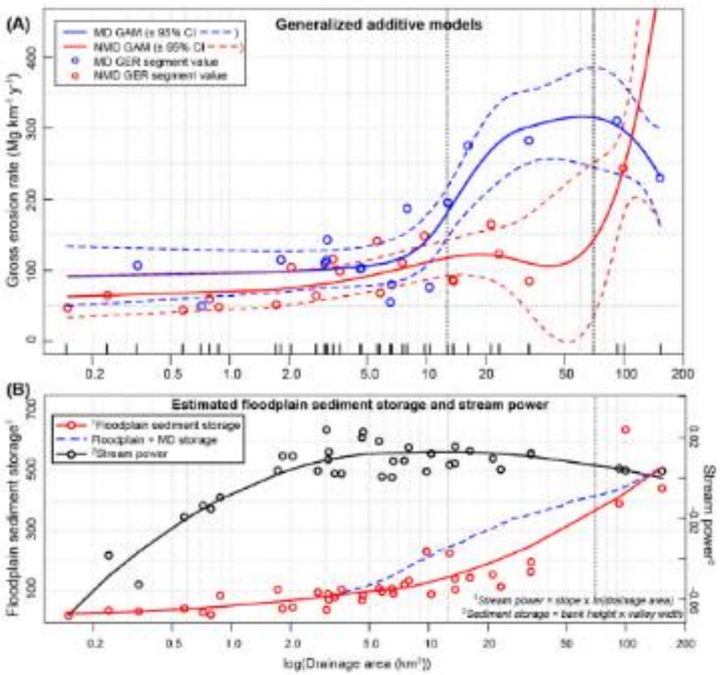
The balance of bank erosion and floodplain deposition is becoming predictable by reach geomorphology

Schenk et al. 2013



Bank erosion and floodplain trapping fluxes increase with drainage area

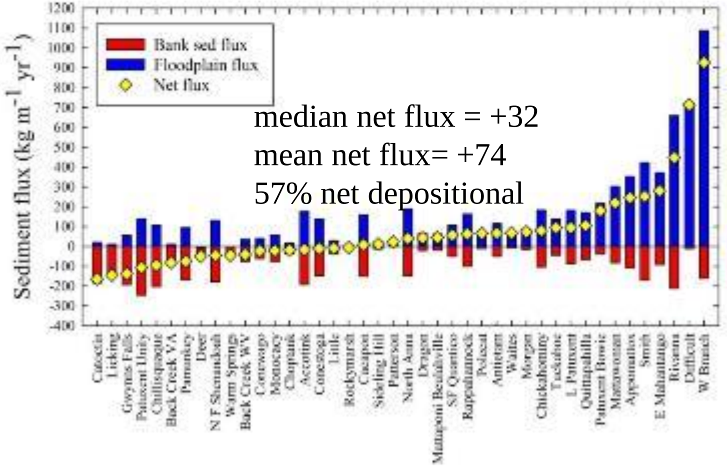
Donovan et al. 2016



USGS *Source, transport, delivery*

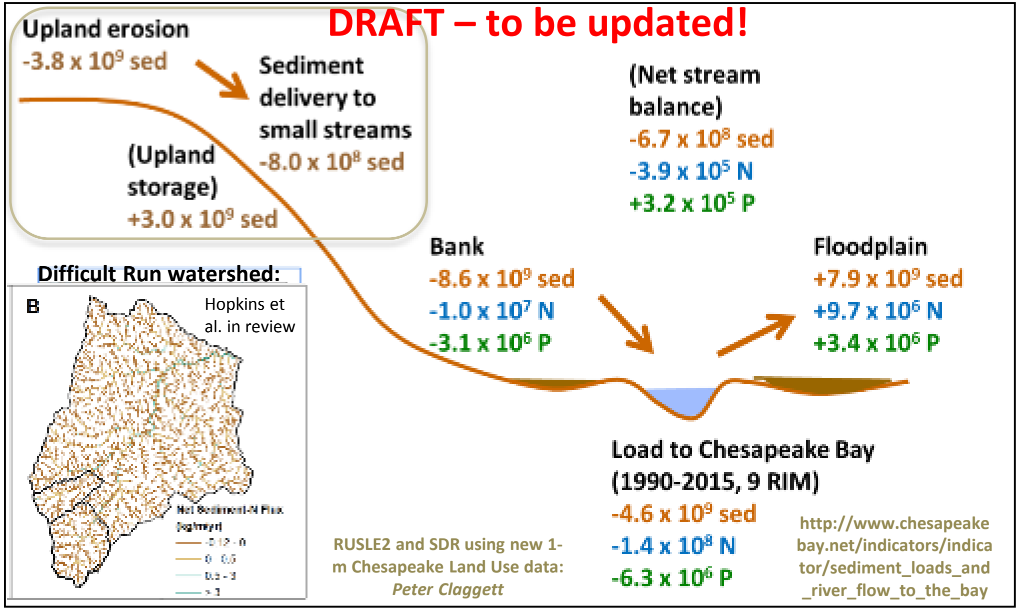
Stream internal fluxes: banks and floodplains

1. The long-term balance of bank erosion and floodplain deposition varies greatly



2. But is predictable from reach geomorphology and watershed hydro, soil and land use characteristics

3. Allowing prediction of fluxes for every NHD+ stream reach in the entire Chesapeake watershed: generating a sediment budget



USGS *Source, transport, delivery*

Noe et al. in prep.

Stream internal fluxes: in-channel

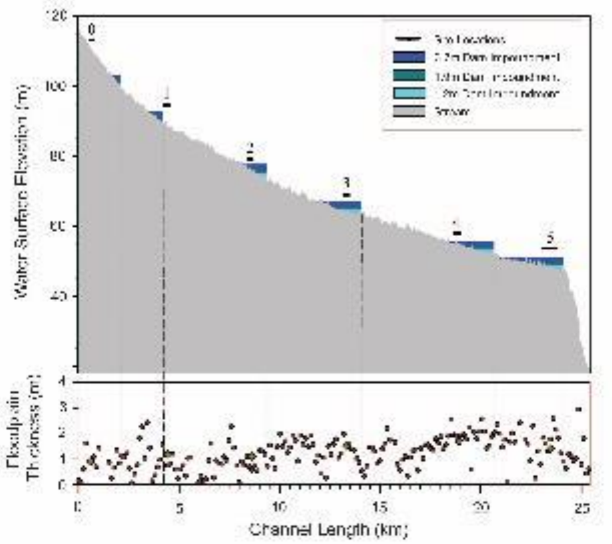
Stream bed and point bar erosion and deposition dynamics are typically **highly variable** and a small proportion of a watershed's **sediment budget**

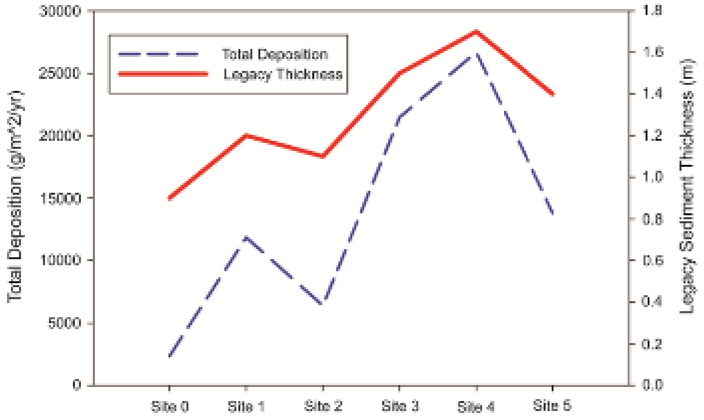
(Gellis et al. 2014, 2017)

USGS *Source, transport, delivery*

Floodplain storage

The example of Difficult Run, VA (Hupp et al. 2013)





The Difficult Run floodplain is composed of fill/legacy sediment. However the (at least six) historic mill ponds were not requisite for substantial deposition on floodplains, they remain active fluvial features not terraces. The similarity between active deposition and legacy thickness suggests there have been no regime changes and that underlying watershed parameters (rather than mill dams) have exercised strong control on fluvial processes in the past and present.

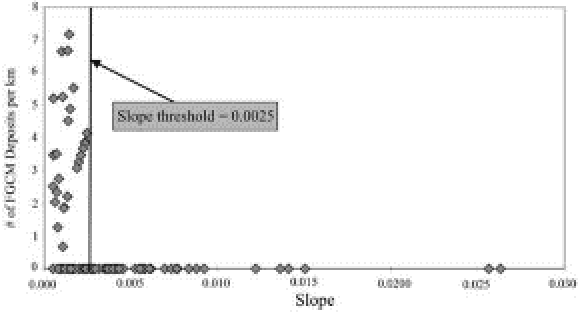
Difficult Run stores on average 132 m^3 per meter of reach, which roughly indicates **2.6 million m3/y of storage between Sites 0 and 5 (approx. 20 km).**

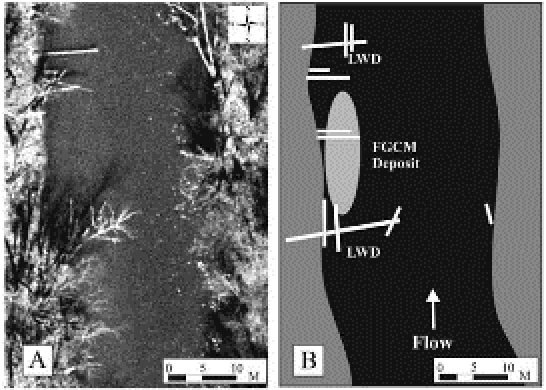
In-channel sediment storage

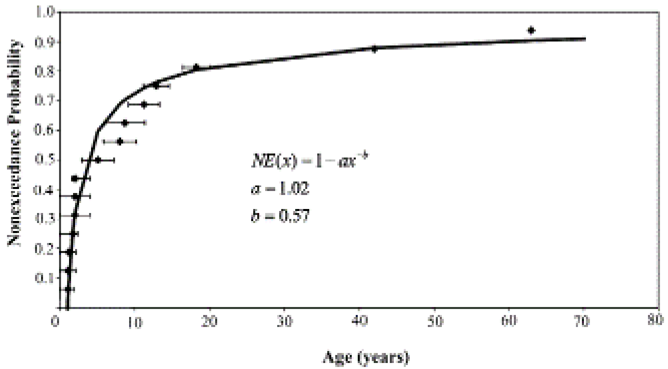
Sediment can be stored within the margins, in point bars, or in the channel bed itself

(Skalak and Pizzuto, 2010)

- Significant quantities of sediment (17% of the load by volume) can be stored in the active margins and **usually conditioned by large wood in the channel**
- **Storage can range from years to decades** and is **controlled by channel morphology such as slope**
- Very high in organic content and primarily sand, silt and clay

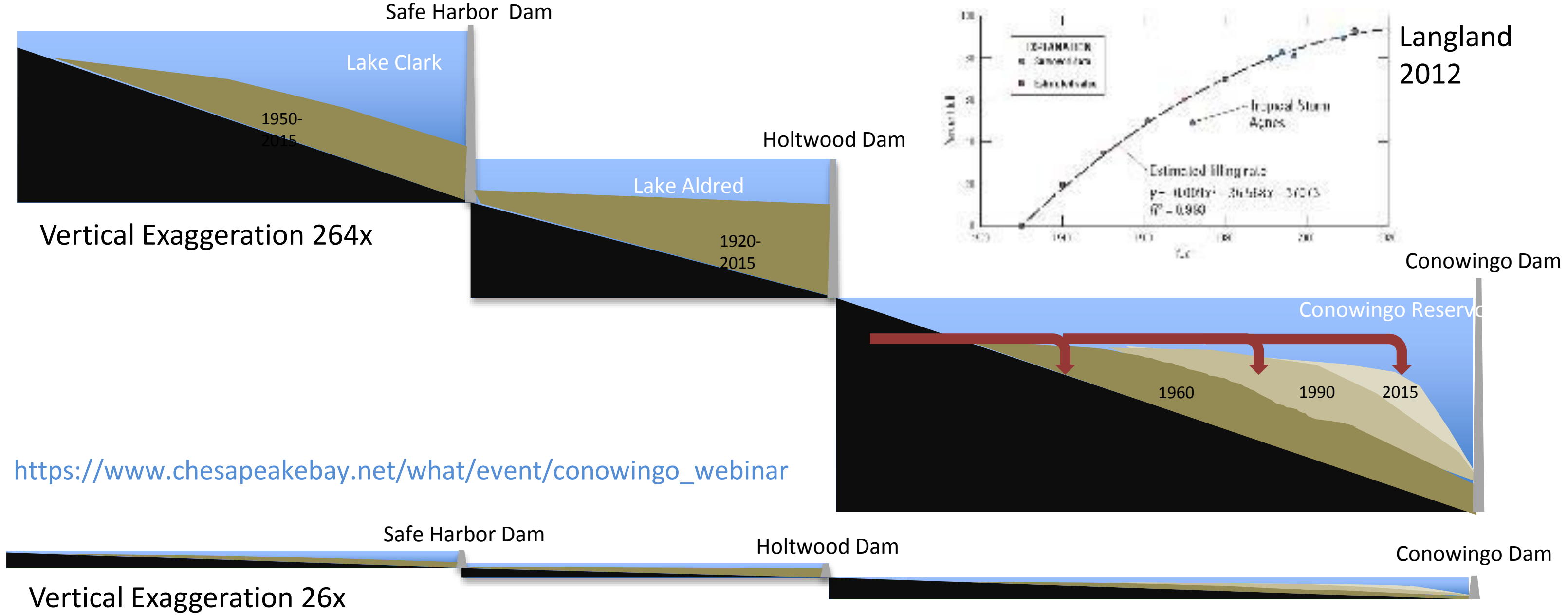






Source, transport, delivery

Sediment infill in the lower Susquehanna reservoirs



https://www.chesapeakebay.net/what/event/conowingo_webinar

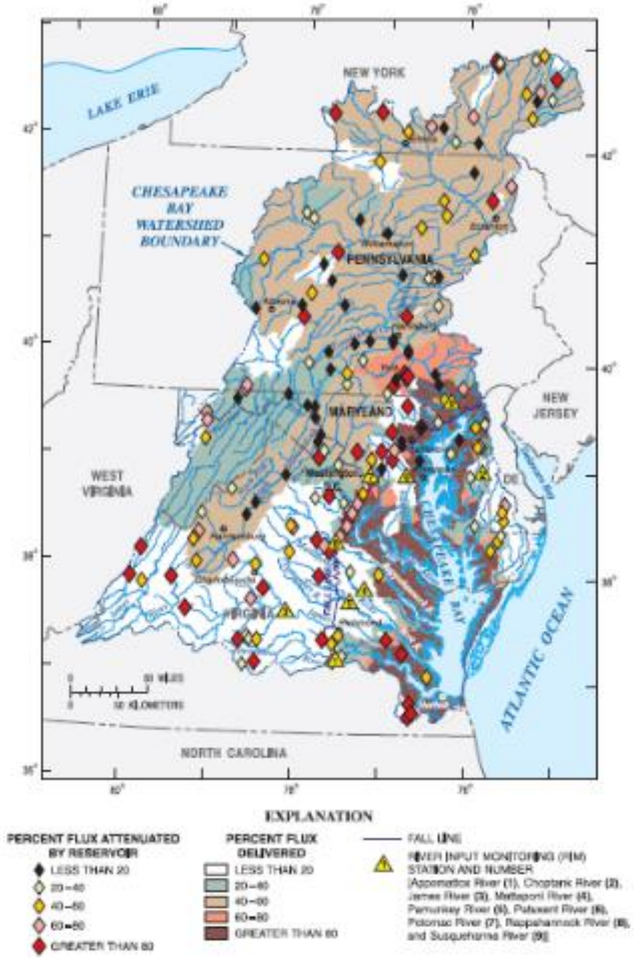
- **Dams have reduced sediment loads by ~60 percent in last 100 years.**
- LSUS River Reservoir system sediment capacity has been steadily declining and is in a state of **“dynamic equilibrium”** (Hirsch, 2012, Langland, 2014)
- Averaging over a range of Susquehanna flows, **approximately 30% of sediment transported to Chesapeake Bay is likely from the reservoirs; 70% is likely from the watershed** (roughly 1970-2106 time frame)

USGS *Source, transport, delivery*

Stream internal fluxes: Reservoirs

SPARROW identifies that **reservoirs trap 29% of sediment** delivered to streams in the Chesapeake watershed

(Brakebill et al. 2010)



USGS *Source, transport, delivery*

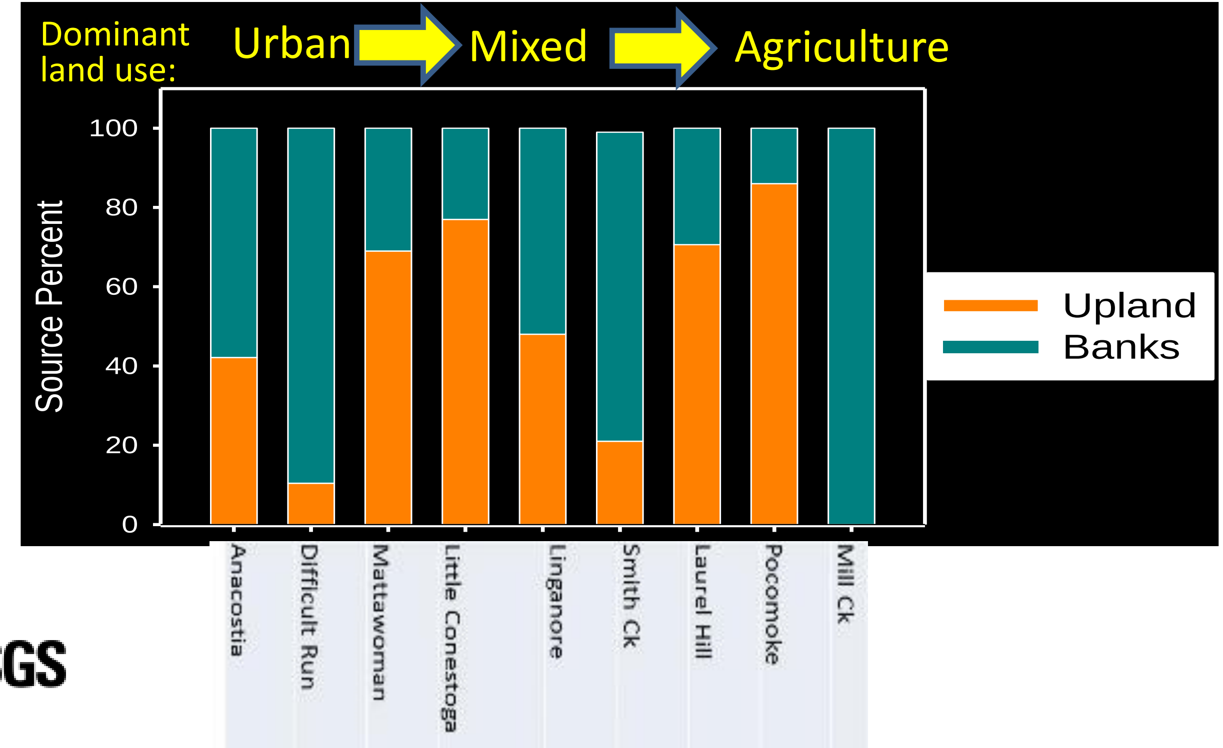
Integrative understanding of sediment sources, transport, and delivery

What are the most important sources of sediment?

How long does it take to get to the Bay?

Fingerprinting to ID sediment sources

Sediment fingerprinting studies (n=9) for streams in the Chesapeake Bay Region indicate that **sources of suspended sediment are highly variable with no discernable trend with land use**



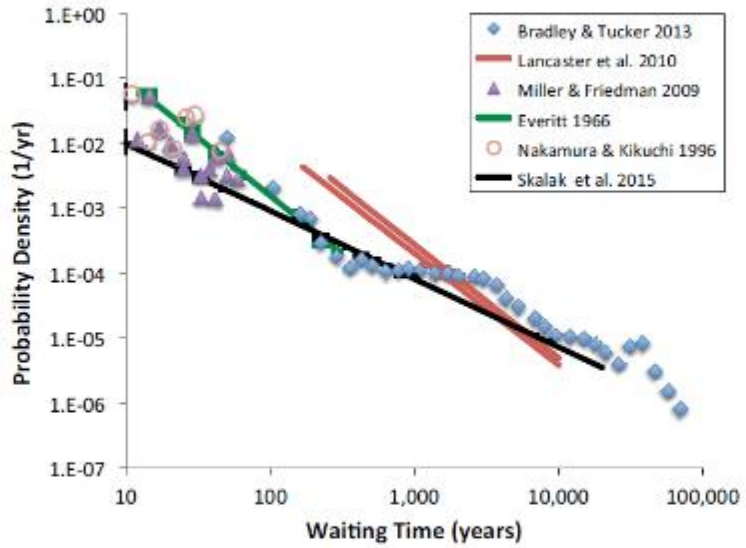
Gellis et al., 2009, Banks et al., 2013; Devereux et al., 2010; Massoudieh et al., 2012; Sloto et al., 2012; Gellis and Noe , 2013; Cashman et al. ,In review; Gellis and Gorman-sanisaca, In review

Upland includes all sources outside the channel – (cropland, pasture, forest, streets, construction sites, dirt roads, ditch beds)

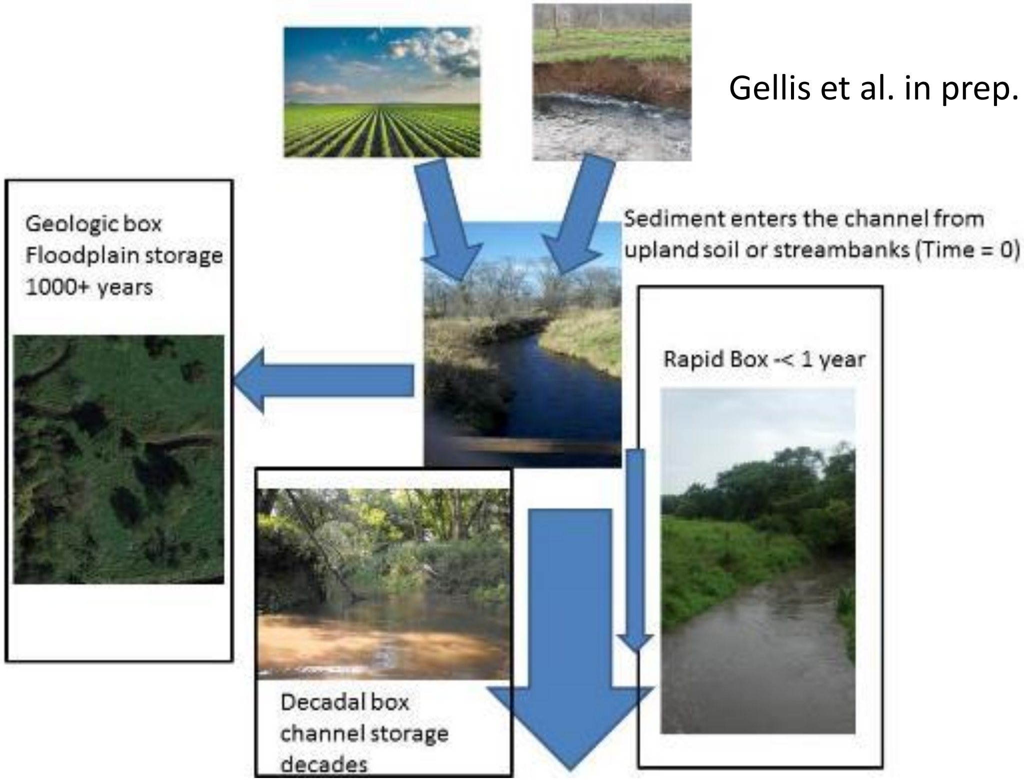
USGS

Sediment transit times

Sediment transit times, from erosion to storage zones, can be thought of as a 3-box model:
geologic, decadal, and rapid, each with different management implications



Pizzuto et al. 2017

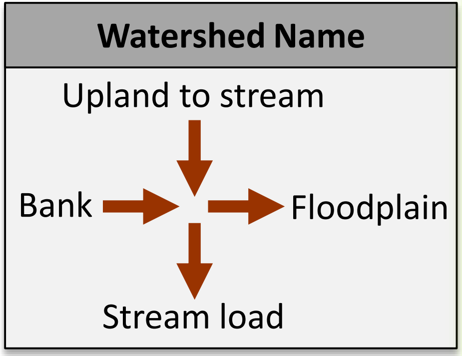


Gellis et al. in prep.

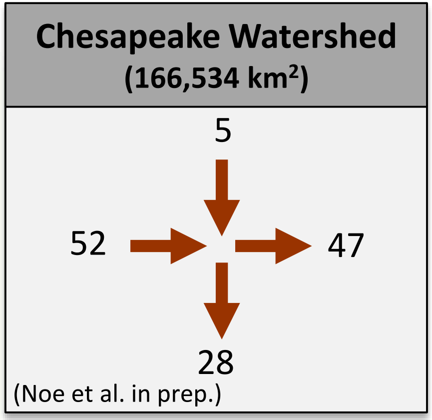
USGS *Lag times*

Holistic picture from watershed sediment budgets

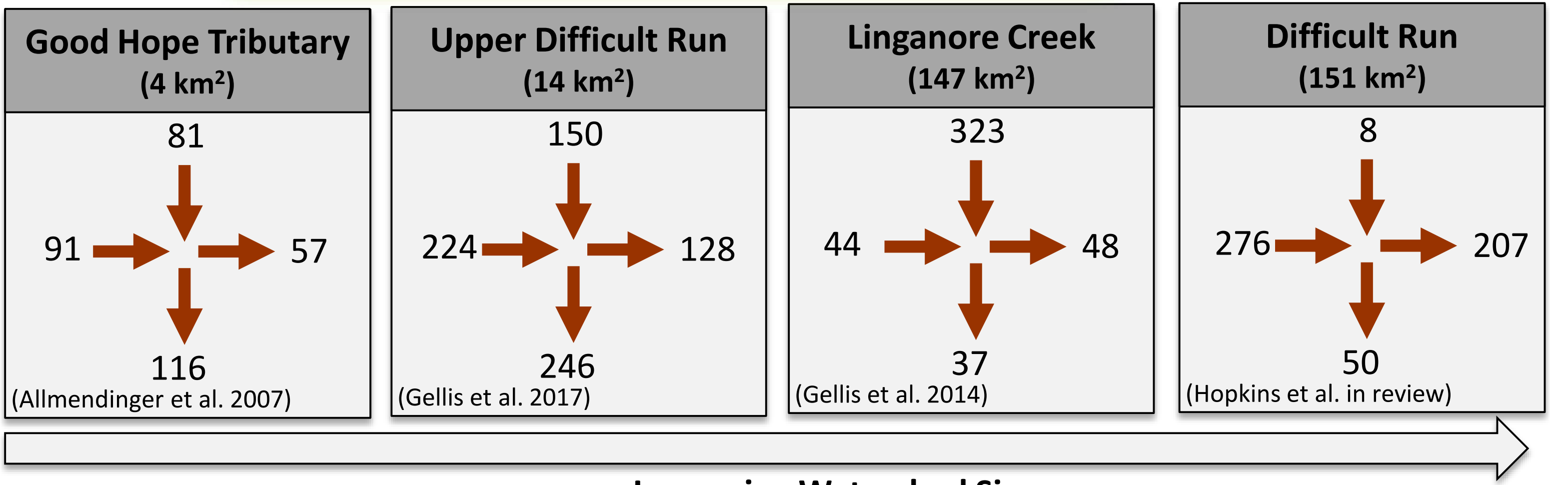
Legend



- **Bank erosion slightly greater than floodplain trapping, both are similar or greater than stream load**
- **Upland erosion inputs to streams highly variable**
- **Depends on watershed size and land use**



Fluxes are in Mg/km²/yr)



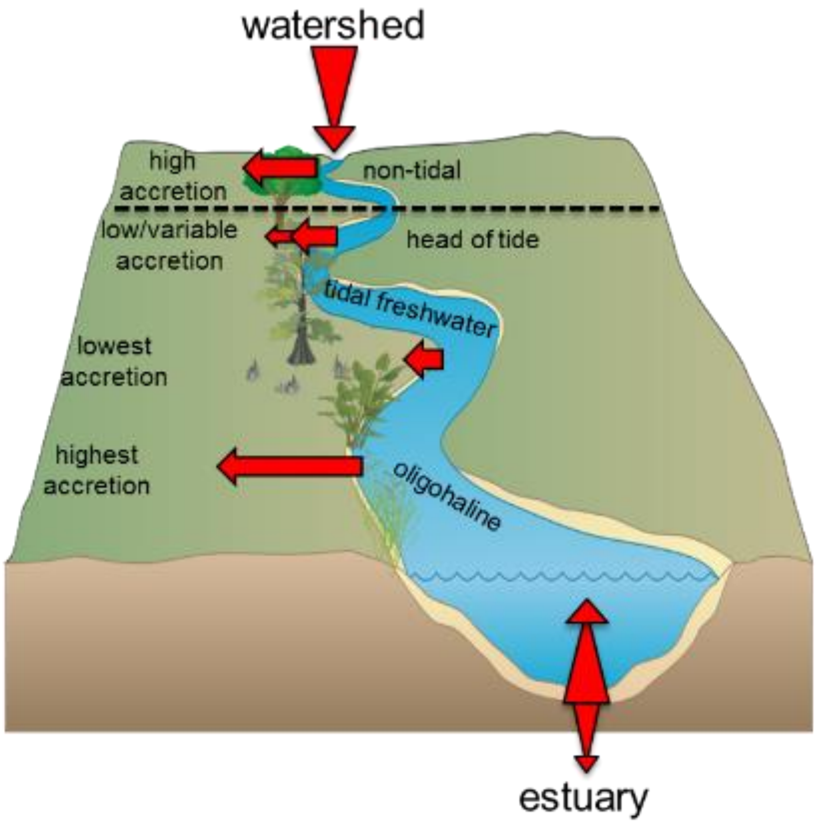
USGS

Increasing Watershed Size

Watershed delivery to the Bay

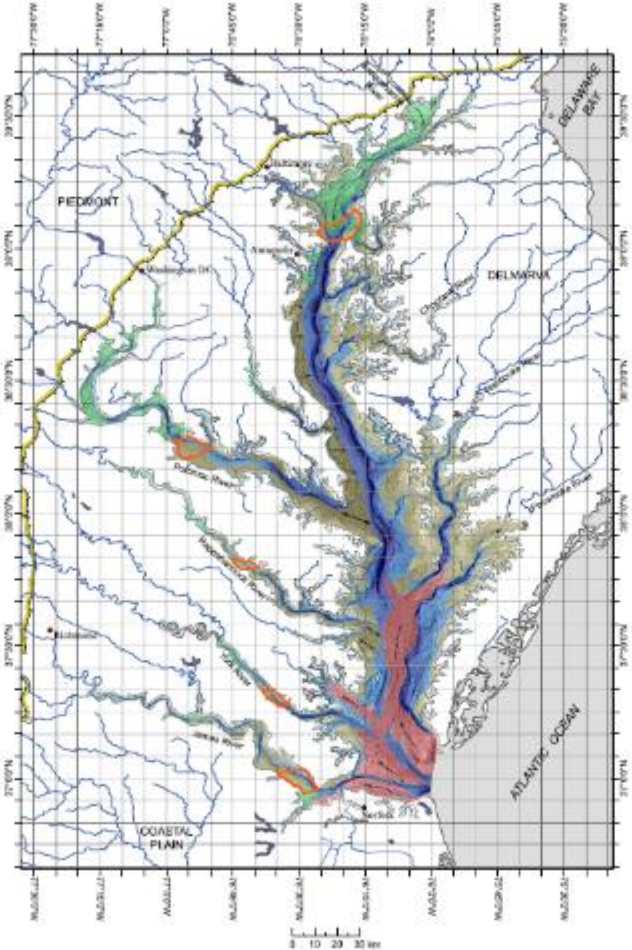
High rates of sediment trapping by Coastal Plain nontidal floodplains and head-of-tide tidal freshwater wetlands creates a **sediment shadow in many tidal rivers, limiting sediment delivery to the main Bay**
(Noe and Hupp 2009, Ensign et al. 2015)

Magnitudes of sediment sources and trapping change along tidal river gradient:



Watershed delivery to the Bay

Sources of sediment within the Chesapeake Bay include river inputs, coastal erosion, and marine inputs, depending on location



USGS
Open-File Report
2004-1235

Best management practices

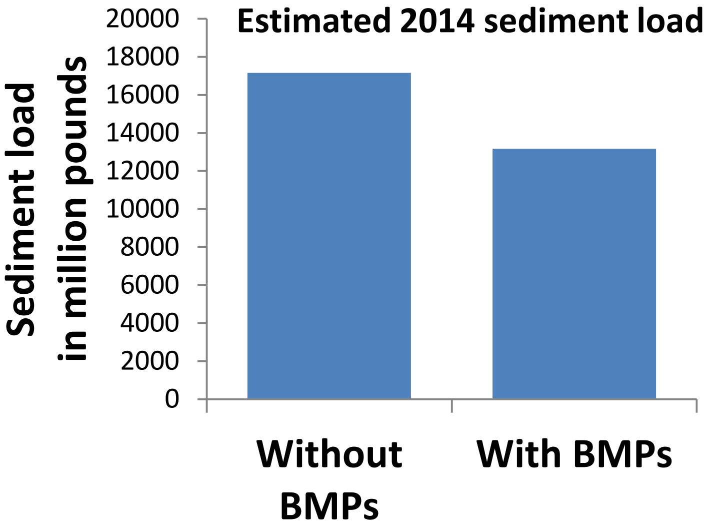
How watersheds managed to reduce sediment loads to meet the TMDL?

Soil conservation or stormwater controls in uplands?

Stream restoration?

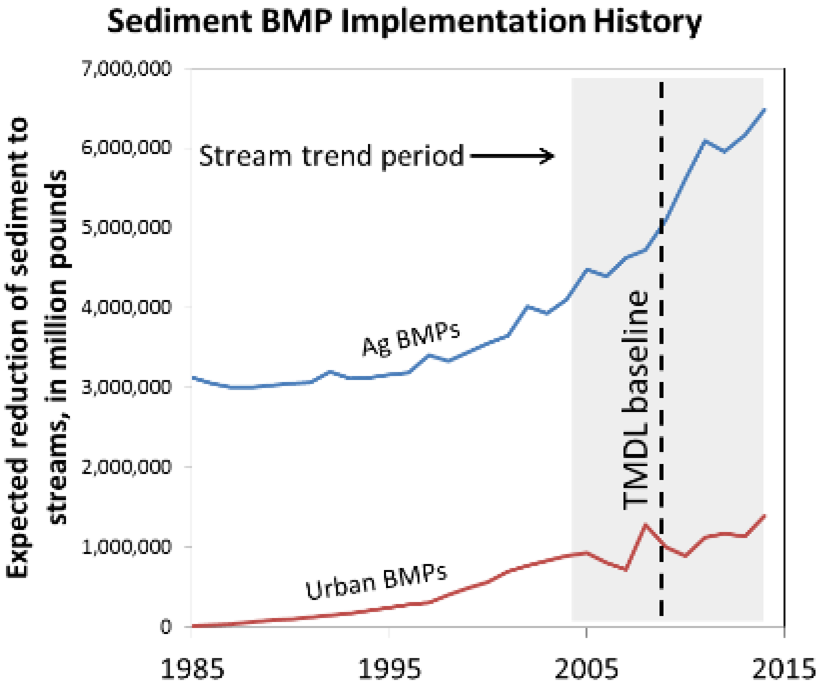
Best management practices in the Chesapeake Bay watershed

Results from the Chesapeake Bay Watershed Model v5.3.2



Ag BMP implementation has accelerated from 1985 to 2014, and is expected to reduce total sediment load to streams by 19%.

Urban BMP implementation is expected to reduce total sediment load to streams by 4%.



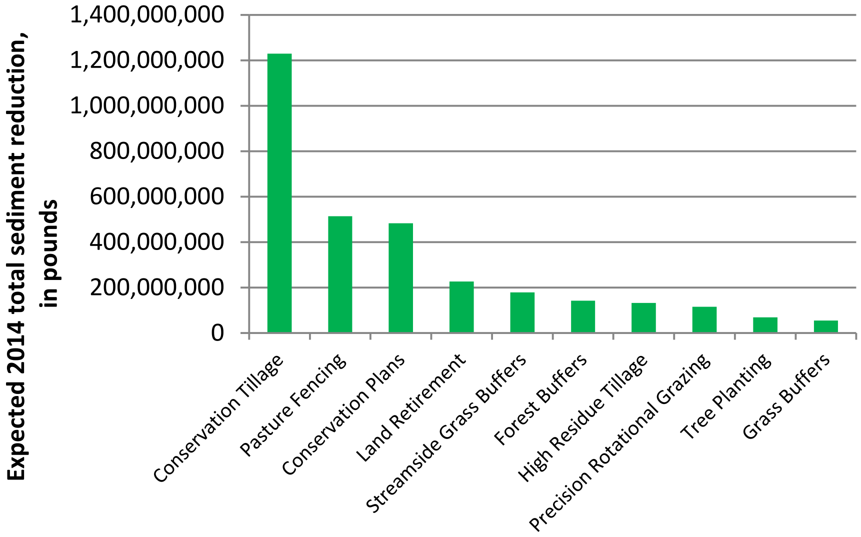
BMPs are estimated to have reduced the sediment load to streams in the Chesapeake Bay watershed by about 23% in 2014.

USGS *BMPs*

Sekellick et al. in review

Best management practices in the Chesapeake Bay watershed

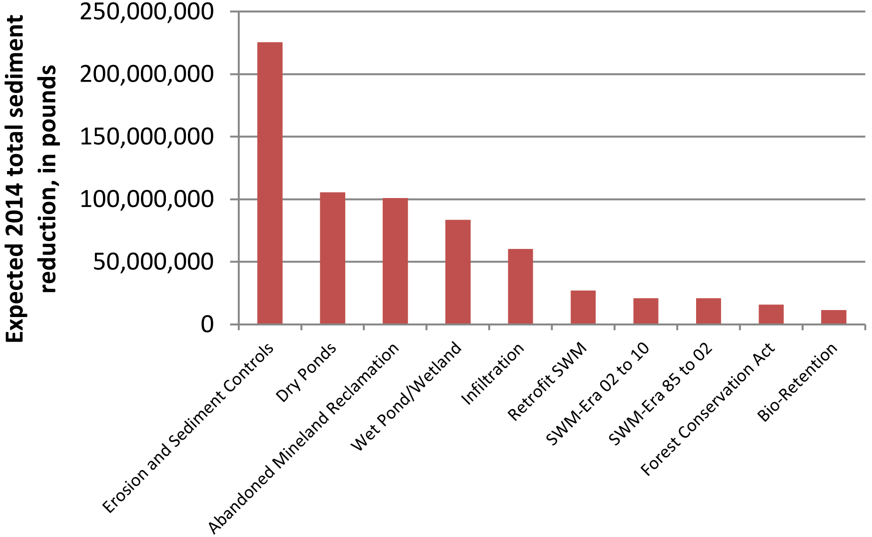
Top 10 Sediment Reducing Agricultural BMPs



Results from the Chesapeake Bay Watershed Model v5.3.2

The two urban BMPs with the greatest reduction in sediment loadings rely on intercepting sediment and reducing erosion.

Top 10 Sediment Reducing Urban BMPs



The principal BMPs for reducing agricultural sediment loads to streams have a wide variety of modes of action.

Sekellick et al. in review

Review of BMP sediment removal efficiencies

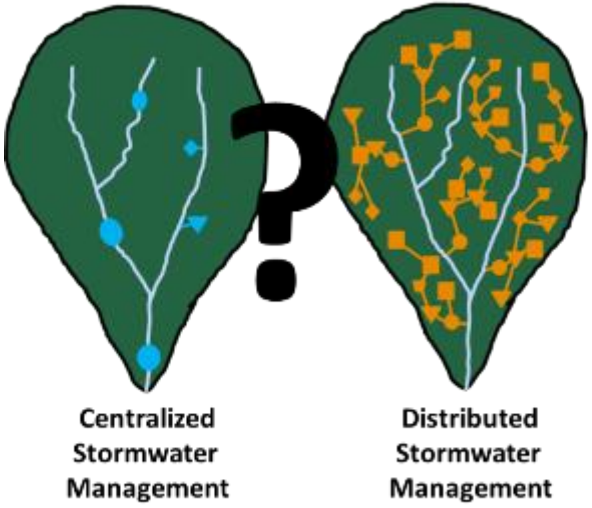
Wide ranges of pollutant removal efficiencies reported for most BMPs, especially urban BMPs.

Limited number of studies specific to Chesapeake Bay states.

Lui et al. *Science of the Total Environment* 2017

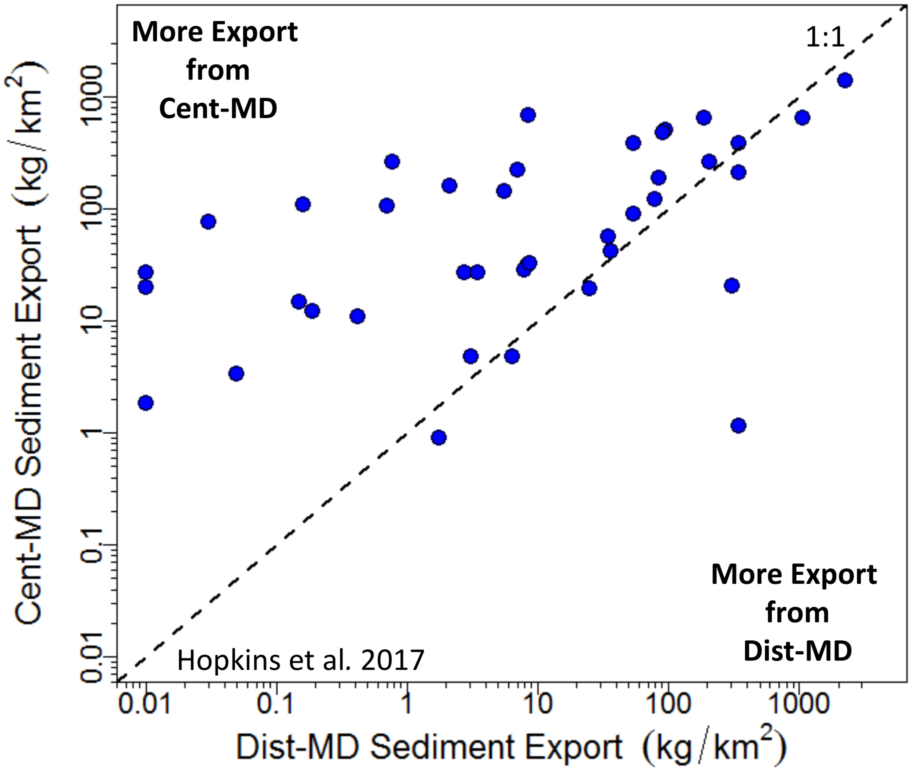
BMPs	TSS Reduction Range	Number of Studies	Citation
Urban BMPs			
Sediment and Erosion Control	46 - 99%	20	Simpson and Weammert 2009
Dry Detention Basins	-52 - 98%	20	Simpson and Weammert 2009
Dry Extended Basins	30 - 85%	5	Simpson and Weammert 2009
Wet Ponds and Wetlands	-78 - 99%	80	Simpson and Weammert 2009
Constructed Wetlands	57 - 99%	8	Cronk 1996
Bioretention/Rain Garden	47 - 99%	17	Ahiablame et al. 2012
Bioretention/Rain Garden	-170 - 96%	4	Dietz 2007
Bioretention/Rain Garden	54 - 99%	12	Davis et al. 2009
Bioretention/Rain Garden	47 - 100%	40	LeFevre et al. 2014
Bioretention/Rain Garden	-170 - 100%	14	Liu et al. 2014
Permeable Pavement	58 - 94%	10	Ahiablame et al. 2012
Swale Systems	30 - 98%	5	Ahiablame et al. 2012
Agricultural BMPs			
Buffer Strip	2 - 100%	54	Arora et al 2010
Buffer Strips	0 - 100%	16	Reichenberger et al 2007
Grass Buffer Strips	53 - 98%	11	Dorioz et al. 2006
Grass Strips	24 - 97%	7	Mekonnen et al. 2015
Grassed waterway	65 - 97%	3	Mekonnen et al. 2015
Shrub and tree buffer	45 - 100%	7	Mekonnen et al. 2015
Vegetated Buffers	45 - 100%	31	Lui et al. 2008
Vegetated Buffers	15 - 100%	20	Yuan et al 2009
Streamside forest buffer	21 - 97%	37	Sweeney and Newbold 2014
Riparian Buffer Strip	75 to 94%	16	Simpson and Weammert 2009

Case Study: Urban BMPs in Clarksburg, MD



Storm event sampling indicated **less sediment export from watershed with distributed stormwater BMPs** compared to watershed with centralized stormwater BMPs, especially for small rain events.

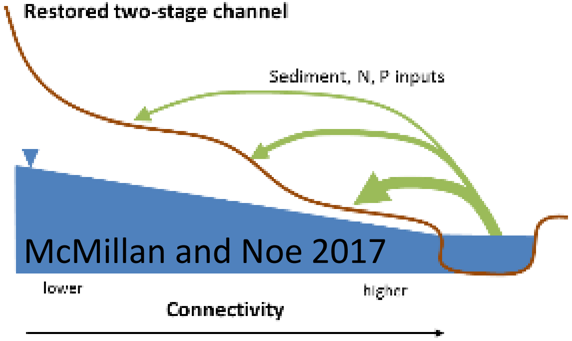
Storm Events in Summer 2011-2012

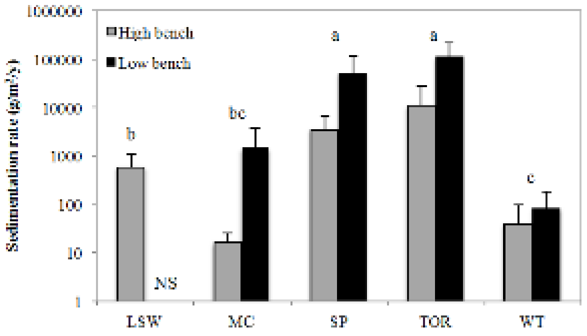


Case study: stream BMPs

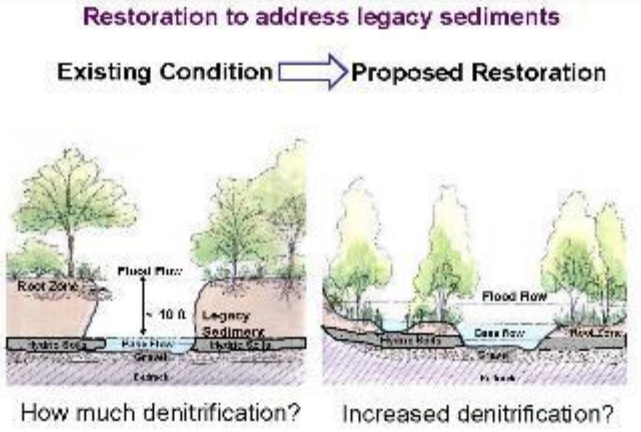
Preventing bank erosion and reconnecting floodplains works

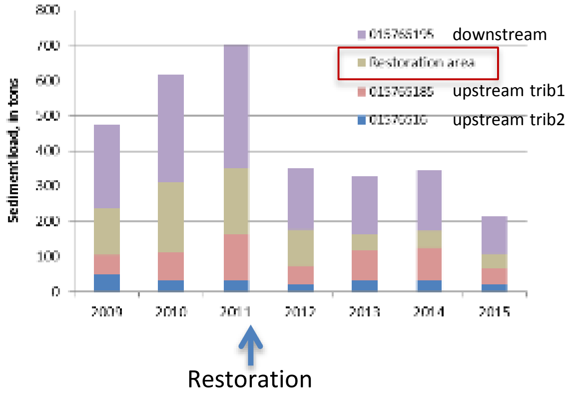
Stream geomorphic 'restoration' (e.g. Natural Channel Design) can be effective at increasing sediment trapping through floodplain creation (Charlotte, NC example)





Removal of legacy sediment reduces downstream sediment load (Big Spring Run, PA example)





Mike Langland, written commun., 2017

USGS *BMPs*

Scientific tools

Data

- Suspended sediment, bed load, rates of sediment erosion and trapping

Sediment fingerprinting

- SED_SAT

Sediment budgets

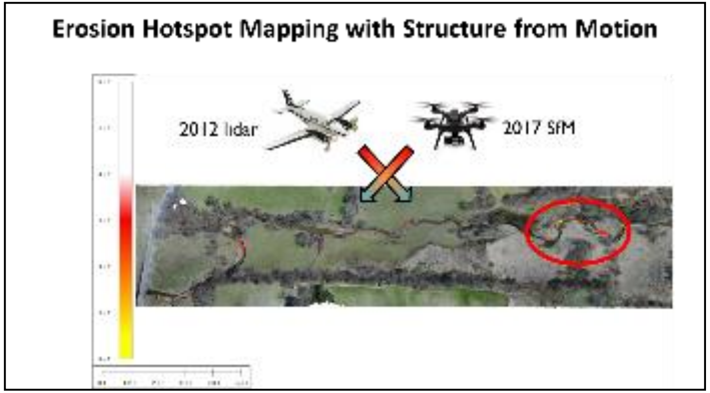
- Individual studies of erosion and deposition rates across watersheds
- Combined inference with fingerprinting

Models

- CB Watershed Model (now Phase 6)
- SPARROW
- SWAT
- 1-D Transport and storage
- Chesapeake Floodplain (and Bank) Network

Geomorphic characterization

- LIDAR, SFM, FACET, surveying, bathymetry, photogrammetry, etc.



A robust toolkit is growing and refining … go observe and model your watershed!

Sediment simulation in Phase 6 WSM

RUSLE = Edge-of-Field Loads

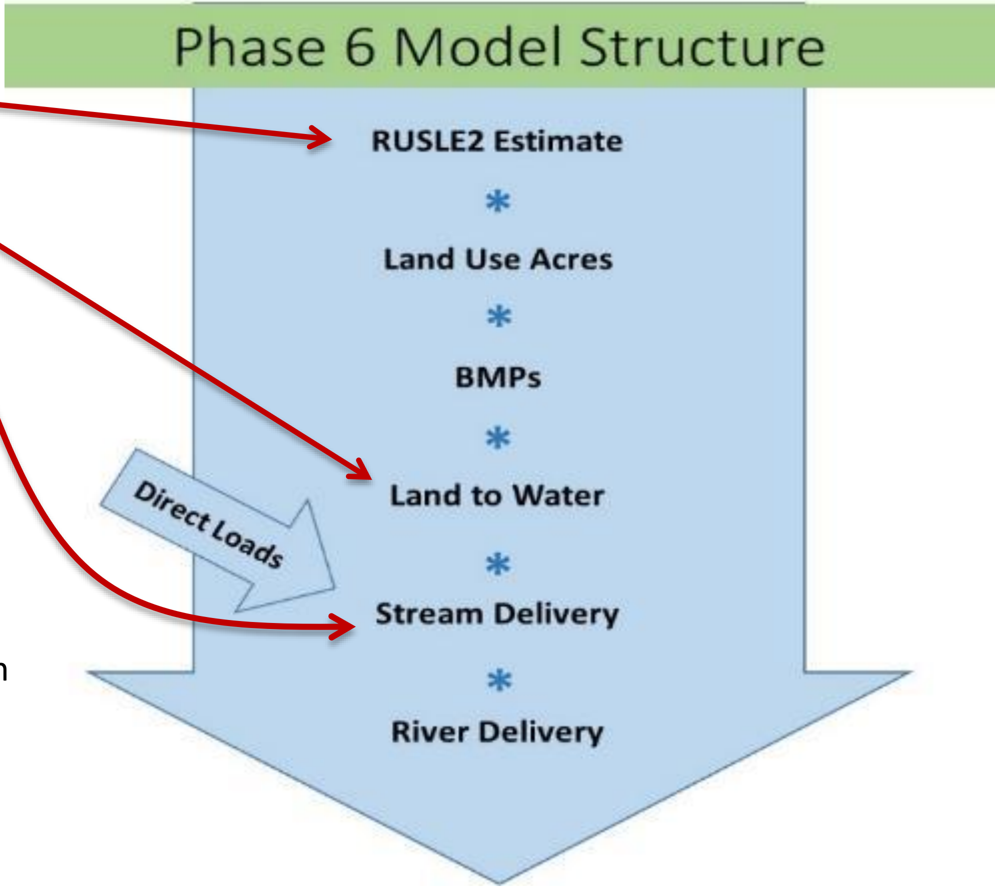
- 10 m pixel of land use

Interconnectivity Metric for Land-to-Water

- Calculation related to Slope, Area, Flowpath Length, and Roughness

Stream Delivery – based on USGS Chesapeake Floodplain Network

- Apply average bank erosion per meter to NHD streamlines
- Assume that equal floodplain deposition takes place in the streams
- Deposition affects bank erosion loads and terrestrial loads proportionally, creating a stream sediment delivery ratio for each watershed.



State of the science

Measurement techniques

- Different techniques (e.g. sediment budget methods) can yield different results in space and time
- **Can target hot spots of erosion, erosion sources, and trapping zones**
- **Quantifying suspended sediment loads in response to management actions**
- Scientific expertise for addressing management questions is growing and available

What is the least certain elements of our conceptual model?

- Time in storage of different zones (e.g. floodplains, in-channel) in differing watersheds, ID of quick responses
- Interactions of sediment transport and storage with phosphorus
- Balance of alluvial storage and erosion and magnitudes compared to downstream loads
- Predicted vs. observed changes in river loads associated with BMPs
- How does an individual BMP affect downstream sediment processes?

Summary

How to guide management actions:

Scale, Time, and Land Use

Geology and historical land use generated a physical template that current land use, and climate, in addition to management, are acting upon to control the sediment delivery to the Chesapeake Bay.

Variations in the temporal and spatial scale of these factors and landscape processes interact in complex ways and require further study to in order to improve predictability of sediment sources, transport, fate and BMP effectiveness.

Scale-dependent factors influencing management action choices:

Sediment sources

- Piedmont, urban and agriculture land use, headwater streams are all important

Transport times and lags

- Active sediment storage can delay detection of effects of BMPs on sediment loads

BMPs

- Wide range in efficiencies, but many are effective, although trends in stream loads are not consistent
- Improving knowledge of sources and lags can help target BMP type and locations

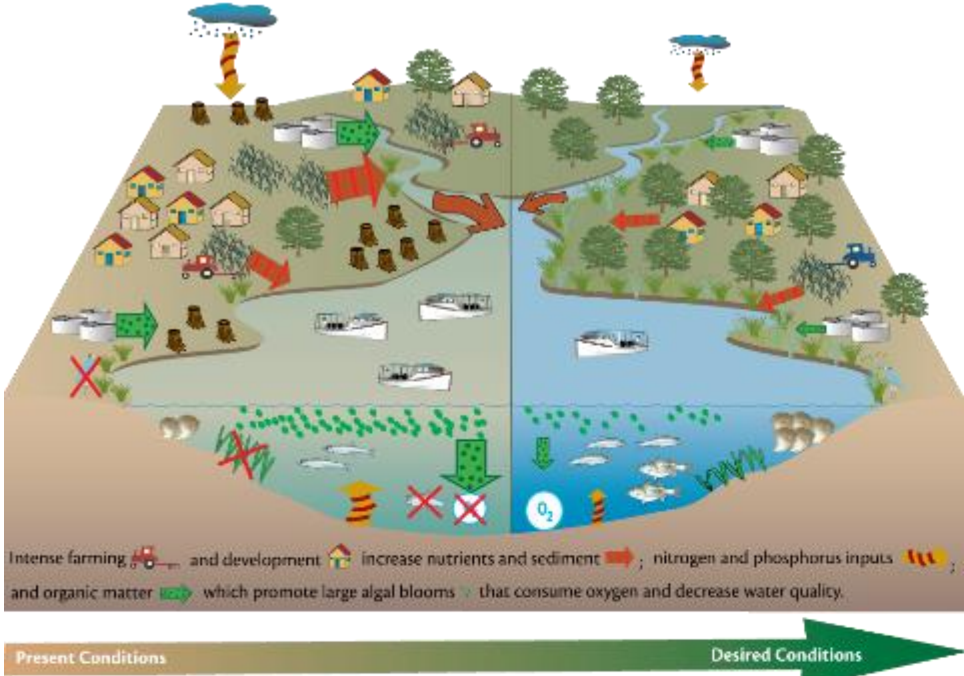


Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Lane, H., J.L. Woerner, W.C. Dennison, C. Neill, C. Wilson, M. Elliott, M. Shively, J. Graine, and R. Jeavons. 2007. Defending our National Treasure: Department of Defense Chesapeake Bay Restoration Partnership 1998-2004. Integration and Application Network, University of Maryland Center for Environmental Science, Cambridge MD.

USGS

The Sediment Story: take home points

Excessive sediment harms fish and wildlife in the Chesapeake Bay and its watershed

Three important geomorphic principles to guide management:

Scale	Sediment started in uplands and is now moving through stream storage compartments Sediment processes differ in headwater streams than in larger rivers **Sediment 'hops and rests' downstream**, in and out of different storage zones (like floodplains), trapping large amounts of sediment (and nutrients), and **causing lag times (sometimes fast, often slow)** of response to management actions
Time	**Historical legacy matters** for understanding current sediment issues, and may impact BMP and management effects on loads
Land Use	Nutrients and other pollutants are attached to sediment **Agricultural, developed** land, and **stream banks** are all **important sources of sediment**, but locally and temporally variable Based on models, **BMPs are expected to have reduced the 2014 sediment load to streams by about 23%** in the Chesapeake Bay watershed

New scientific advances continue to improve our ability to understand and manage local and regional sediment problems

USGS